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EARTHQUAKE IN MEXICO

HEARING

BEFORE THE

SUBCOMMITTEE ON
SCIENCE, TECHNOLOGY, AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

NINETY-NINTH CONGRESS

FIRST SESSION

ON

THE EARTHQUAKE IN MEXICO

OCTOBER 3, 1985

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EARTHQUAKE IN MEXICO

THURSDAY, OCTOBER 3, 1985

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE,
Washington, DC.

The subcommittee met, pursuant to notice, at 10:25 a.m., in room SR-253, Russell Senate Office Building, Hon. Slade Gorton (chairman of the subcommittee) presiding.

Staff members assigned to this hearing: Cassie Phillips, staff counsel; Chris Ostrom, professional staff member; and Pat Windham, minority professional staff member.

OPENING STATEMENT BY SENATOR GORTON

Senator GORTON. Since our entire first panel is here, we will start.

Good morning, and welcome to this hearing of the Science, Technology, and Space Subcommittee of the Senate Commerce Committee.

Two weeks ago today, one of the largest earthquakes in North American history shook Mexico City and the surrounding areas. The epicenter of this earthquake, which measured 8.1 on the Richter scale, was 250 miles southwest of Mexico City. The following night a second large earthquake measuring 7.5 on the Richter scale hit in the same area.

The effect of these massive earthquakes on such a densely populated area—some 18 million people live in the Mexico City metropolitan area—has been tragic. News reports indicated that as many as 10,000 lives may have been lost. It has been estimated that over 7,000 buildings were damaged, and about 450 of those have been destroyed.

The buildings which failed to withstand the impact of the earthquake included federal buildings, schools, and hospitals. Financial loss from the destruction of the buildings alone has been estimated to be at least $2 billion. The destabilizing effect of the disaster on the banking and financial community, and the tourist industry Mexico's second largest industry, is still taking its toll.

This earthquake has been a truly catastrophic event, causing untold human tragedy and enormous financial loss. Such an event could occur, and indeed some time in the future it is quite likely to occur, somewhere in the United States. Thirty-nine States, in fact, are exposed to the threat of a major earthquake.

For this reason, it is imperative that we begin immediately to draw upon the Mexican experience to learn as much as we can

about the effectiveness of our own earthquake preparedness and mitigation programs.

This hearing will begin with a panel of representatives of the Federal agencies which are conducting activities under the Earthquake Hazards Reduction Act. The agencies will include the Federal Emergency Management Agency, the U.S. Geological Survey, the National Science Foundation, and the National Bureau of Standards.

Just last March we heard testimony from these same agencies during a hearing considering the reauthorization of the earthquake program. Last Monday, I am pleased to say, the President signed that authorization bill into law.

All four agencies have received preliminary reports from teams of experts who are in Mexico City surveying the effects of that earthquake. They will be able to tell us about the Mexican earthquake, and response, and about lessons we can learn that either reinforce or suggest possible weaknesses in the elements of our own earthquake programs.

Following the Federal agency panel, we will hear a firsthand account of what happened in Mexico from two earthquake experts who have just returned from Mexico City. Both were sent to Mexico as part of a National Academy of Sciences team, the mission of which was to survey the impact of the earthquake before much of the evidence was destroyed during the cleanup effort.

One is a structural engineer. The other is an expert in preparedness and disaster response. Both are probably exhausted, and we truly appreciate their willingness to testify.

The third panel represents the point of view of those who work on earthquake preparedness and mitigation programs at the regional, State, and local levels.

A final panel will discuss the complex issue of earthquake insurance and the effect of a major earthquake on the insurance industry and financial community.

This hearing was called on rather short notice, and I thank all the witnesses for their enthusiastic cooperation. I should also emphasize that these reports from Mexico City are still preliminary. A great deal of information from Mexico will be collected and analyzed, and many reports will be forthcoming. This committee will continue to have great interest in those findings.

At this point I will ask Senator Gore whether he would like to make an opening statement.

OPENING STATEMENT BY SENATOR GORE

Senator GORE. Yes, Mr. Chairman. Thank you very much.

Two weeks ago today the world witnessed one of the worst natural disasters of recent years. On September 19, an earthquake registering 8.1 on the Richter scale struck the western coast of Mexico. The tremors from that quake and a second quake the following day spread throughout central Mexico and devastated the Nation's capital, Mexico City, even though that city lay nearly 200 miles from the epicenter of the quake.

The damage caused Mexico City by the quake was extensive. Hundreds of buildings were destroyed. Thousands of people were

injured or left homeless. Officially over 5,000 people died, and the number could be much, much higher.

The tragedy of Mexico City's earthquake illustrates all too starkly the devastation that can result when a city is prepared to cope with neither the eventuality of an earthquake nor the tremendous damage that can be caused by one.

Indeed, the city lay vulnerable to the earthquake that struck it like a sad, helpless giant. Many of the buildings were structurally incapable of withstanding an earthquake, and the ground upon which the city stands actually amplified the shockwaves.

Even worse, once the disaster had occurred, the city proved incapable of responding quickly to the disaster. Fortunately, Mexico has received aid from many of its fellow nations, including the United States, and bit by bit the city is recovering. There are many lessons that we in the United States should learn from the earthquake that devastated Mexico City.

Foremost among these is that we must do everything within our ability to assure that no city or area in this country suffers like Mexico City because of an earthquake. We must take every step to make certain we are prepared for the eventuality of earthquakes, and that we are capable of responding swiftly and effectively to them when they occur.

Earthquakes are not a possibility. They are a certainty, at least for the millions of people in this country who live near fault lines. I am especially concerned about earthquake preparedness in America because many of those people live in my home State of Tennessee and in the surrounding areas that lie near the New Madrid fault.

As chairman of the House Science and Technology Subcommittee on Investigations and Oversight over the last several years, I chaired several hearings on earthquakes in the eastern United States.

Those hearings led me to conclude that not nearly enough is known about the dynamics of earthquakes east of the Rocky Mountains, and that more must be done to increase our understanding of them. But while our knowledge is limited, our past experience with such quakes provides us ample cause for concern.

The most powerful earthquake ever to strike the continental United States occurred along the New Madrid fault in 1811. Centered near New Madrid, Missouri, the Great New Madrid Earthquake actually consisted of three separate earthquakes that rocked the Mississippi Valley on December 16, 1811, on January 23, 1812, and again on February 7, 1812.

It is estimated that the three quakes measured 8.6, 8.4, and 8.7 respectively on the Richter scale. The great New Madrid earthquake was so powerful that it is said to have caused the Mississippi River to run backwards. The shockwaves it produced rang churchbells as far away as Boston.

It has obviously been many years since that quake occurred, and while several earthquakes have occurred over the last 174 years since that time, they have all been much less severe. Nevertheless, the threat of a major earthquake hangs disconcertingly over the residents of the New Madrid region.

It has been estimated that there is a 40 to 60 percent chance that a quake measuring at least 6 on the Richter scale will strike the area before the year 2000. The odds of such a quake occurring before the year 2035 increased to 86 to 97 percent.

The concern about a possible earthquake is especially prevalent in the city of Memphis, the largest city in Tennessee, and in the surrounding west Tennessee counties. Fortunately, because of their foresight and concern, the people of Memphis and west Tennessee are beginning to take steps to minimize the dangers of an earthquake to the area.

Efforts are under way to ensure that buildings are made earthquake proof. Public education programs are being conducted now. The Tennessee Earthquake Information Center located at Memphis State University is doing a tremendous job of monitoring earthquake activity in the region, and keeping the public well informed.

Additionally, a significant step toward earthquake preparedness in the eastern United States was taken in April of last year, when the Federal Emergency Management Agency announced the creation of a Central U.S. Earthquake Consortium.

The Consortium has established an earthquake monitoring center, and assisted in the development of a 5-year earthquake preparedness plan.

We touched upon that plan briefly when Dr. Speck of FEMA testified before the subcommittee earlier this year, and I am anxious to hear more about it from him today.

FEMA has also recently completed a major study of the potential effects of earthquakes on six cities across the United States, and Memphis was one of the cities examined. So I am anxious to discuss that report as well.

Despite the many efforts under way in Tennessee and elsewhere to prepare for an eventual earthquake, more can and must be done. That is one of the main reasons that we are here today, to learn how we can avoid the mistakes that led to the tragedy of Mexico City. We must resolve that a disaster like that which occurred in Mexico City will never happen in this country.

Mr. Chairman, I want to thank you and congratulate you for holding this hearing so quickly after the events in Mexico City. It is important that we begin now to consider what took place there and why.

The witnesses who will testify today will assist us invaluably with our inquiry.

And finally, Mr. Chairman, I want to say how pleased I am that Dr. Arch Johnston of Memphis will testify here today. Dr. Johnston is the director of the Tennessee Earthquake Information Center, and is regarded as one of the foremost experts in this country on earthquakes.

He testified before my subcommittee in the House, and I have worked closely with him and his colleagues at Memphis State on several projects. I look forward to continuing that relationship here as a member of this subcommittee, and I especially look forward to the testimony today.

Thank you.

Senator GORTON. Thank you, Senator.

The distinguished chairman of the full committee, Senator Danforth, has a written statement which will be included in the record at this point, and Senator Hollings has requested that his statement be included in the record of the hearing.

[The statements follow:]

OPENING STATEMENT BY THE CHAIRMAN

Thank you, Senator Gorton, for promptly assembling before the Subcommittee such an impressive panel of experts. The Committee will benefit from the testimony of these who have just returned from Mexico. The tragedy that occurred there two weeks ago serves as a warning to other countries, including the United States, to take a close look at what can be done to increase preparedness and decrease the adverse consequences of a catastrophic earthquake.

Of particular interest to me is the preparedness of the central United States. Running through part of Missouri is the New Madrid Fault. It is along this fault that the strongest known earthquake in the continental United States occurred—the 1811 quake that is estimated to have hit 8.7 on the Richter scale. Perhaps there is much that we can learn from the experience in Mexico that could help avert a similar tragedy in the future.

I would also like to thank the Subcommittee Chairman for inviting Dr. Robert Herrmann, Professor of Geophysics at St. Louis University. I am sure that his analysis of the situation in Mexico, especially the disastrous effects of a large earthquake amplified over very long distances, will prove useful to the Committee.

OPENING STATEMENT BY SENATOR HOLLINGS

Mr. Chairman, as the death toll continues to mount, there is little doubt that the recent earthquake in Mexico will go down as one of the most horrific tragedies of the 20th Century. The massive destruction, the widespread loss of life, and the homelessness it created would severely strain the human and economic capabilities of any nation, let alone our financially-troubled neighbors to the south.

In this respect, if there are any positives to note from Mexico's awful experience—and I would stress that there are very few—then they would surely include the courage of the Mexican people and the dedication of the rescue workers, both Mexican and foreign. Perhaps another is that this catastrophe may teach us how to better prepare for future earthquakes and better respond to them when they occur. This is the reason for this Subcommittee hearing today.

Mexico City was far from unprepared for a major earthquake. It has modern building codes and a comprehensive emergency response plan. In many ways, it seems, those preparations and plans worked. Most buildings in the capital survived, and emergency teams were deployed quickly

Yet questions remain. To begin with, Mexico City lies 250 miles from the quake's epicenter. How could such a distant event create such intense destruction? Are United States cities more vulnerable to distant earthquake than we now believe?

Second, while most buildings survived in Mexico City, many did not, including several hospitals. Utilities—especially long-distance telephone operations—were severely disrupted. Why did these problems occur? Were building codes inadequate, or was the problem one of poor enforcement? Given the fact that designing earthquake-proof buildings is a new and inexact science, what can the Mexican experience teach us about which designs do and do not work? Are American designs adequate?

Finally, press reports suggest that gaps developed in the rescue and response efforts. The need for heavy equipment and extra medical teams exceeded expectations. What do these problems suggest about the adequacy of our emergency response plans in the United States?

I hope that our witnesses today can shed light on these important issues. I realize that it will take time to learn the full lessons of the Mexican earthquake, but it is not too soon to start our examination.

Mr. Chairman, I commend you for holding this hearing and for your leadership in this important area of earthquake preparedness. Your state, like mine, is threatened by seismic dangers. I am pleased that the Subcommittee continues its efforts to understand and deal with this threat.

Senator GORTON. We are now prepared to begin with the Federal panel, starting with Dr. Speck of FEMA, to be followed by Dr. Peck

of the Geological Survey, Dr. Nam Suh of the Science Foundation, and Dr. Lyons of the National Bureau of Standards, in that order.

Dr. Speck.

STATEMENTS OF DR. SAMUEL SPECK, ASSOCIATE DIRECTOR FOR STATE AND LOCAL PROGRAMS AND SUPPORT, FEDERAL EMERGENCY MANAGEMENT AGENCY, ACCOMPANIED BY GARY JOHNSON, ACTING DIRECTOR, DIVISION OF EARTHQUAKES AND OTHER NATURAL HAZARDS; DR. DALLAS PECK, DIRECTOR, U.S. GEOLOGICAL SURVEY, ACCOMPANIED BY DR. JOHN FILSON, CHIEF, OFFICE OF EARTHQUAKE, VOLCANOS, AND ENGINEERING; DR. NAM P. SUH, ASSISTANT DIRECTOR FOR ENGINEERING, NATIONAL SCIENCE FOUNDATION; AND DR. JOHN W. LYONS, DIRECTOR, NATIONAL ENGINEERING LABORATORY, NATIONAL BUREAU OF STANDARDS, ACCOMPANIED BY DR. RICHARD N. WRIGHT, DIRECTOR, CENTER FOR BUILDING TECHNOLOGY; AND DR. E.V. LEYENDECKER, LEADER, EARTHQUAKE ENGINEERING GROUP

Dr. SPECK. Thank you, Senator Gorton and members of the committee. We appreciate the opportunity of appearing before this hearing.

The Mexican earthquake dramatizes that the earthquake hazard threatens us with the greatest catastrophic event we face short of war. Moreover, there is a 50-percent chance that a catastrophic earthquake of the proportions suffered by Mexico will happen in Southern California, if not elsewhere in the United States, within the lifetime of most of the people in this room.

While hopefully we can avoid war, at this point we can at best only reduce the impact of a catastrophic earthquake.

This morning I would like to focus on two things: First, what are we doing about this threat; and second, what have we learned and do we hope to learn from the tragic Mexican disaster.

In 1977, Congress created the National Earthquake Hazards Reduction Program, bringing together the earthquake hazard-related research programs, already well under way, of the three other agencies represented on this panel, with the activities of FEMA, to form integrated and comprehensive Federal program.

I have attached a chart to my written statement which depicts the five elements comprising the program and identifies respective agency responsibilities. FEMA's mission under the program is essentially threefold: first, to effectively fulfill the lead agency responsibilities as envisioned by Congress; second, to develop a capability within State and local governments to prepare for, respond to, recover from, and mitigate against the effects of an earthquake; and third, to ensure that the resources of the Federal Government can be quickly and efficiently mobilized to augment State and local response and recovery efforts following an earthquake.

I will briefly highlight the most noteworthy activities which FEMA is undertaking to fulfill this mission. First, with respect to leadership, FEMA chairs a variety of interagency coordinating mechanisms at both the senior policy and program manager levels.

These have proven to be effective in dealing with the range of issues that the national program faces. FEMA also oversees and co-

ordinates the preparation of and submits on behalf of the President the National Earthquake Hazards Reduction Program annual report and the 5-year plan.

Second, with regard to building State and local capability, as in all matters related to public health, safety and welfare, State and local governments bear the primary responsibility for the protection of life and property in the event of an earthquake.

They, along with individuals and groups in the private sector, are the ultimate users of information and projects generated under the National Earthquake Hazards Reduction Program. FEMA is providing technical and financial assistance to support earthquake hazard reduction activities in all of the Nation's high population risk areas.

These are exemplified by the southern California earthquake preparedness project and the one already mentioned by Senator Gore, the central U.S. earthquake preparedness project.

In addition, to assist State and local governments toward enhancement of their overall emergency management capabilities, FEMA developed the Integrated Emergency Management System, or IEMS, which stresses a functional approach to the management of emergencies across the full spectrum of emergencies and disasters, while at the same time recognizing the unique elements specific to particular emergencies.

The functional approach to comprehensive emergency management was funded last year by approximately $100 million of civil defense funds and direct program and training support to State and local governments. Clearly, the Nation's capability to respond to a catastrophic earthquake has been enhanced by the Civil Defense Program.

Third, concerning Federal mobilization, State and local resources will be inadequate to respond to the effects of a catastrophic earthquake. To meet basic human needs, response of the Federal Government, both from the near geographic area and the entire Nation will be required. Therefore, in recognition of the increasing threat of a catastrophic earthquake in California, as well as the possibility elsewhere, FEMA initiated a response planning effort that involves the entire Federal Government.

The fourth draft for the resulting national plan was exercised in Response 85 this past June, and was based upon a simulated catastrophic earthquake in southern California. The lessons learned from Response 85 will be incorporated into a subsequent draft of the plan, and has just been published within the past several weeks. Future work will initiate development of Federal regional plans and include exercises to maintain and update the national plan.

Additionally, FEMA chairs the Earthquake Working Group in support of the Emergency Mobilization Preparedness Board, which has been addressing national mobilization preparedness issues associated with the consequences of a catastrophic earthquake.

You will find FEMA's program more completely described in attachment 2 to my testimony.

It is important to point out that FEMA has not provided assistance to the Mexican Government to respond to this earthquake disaster, because FEMA does not have any authority to intervene in

Mexico's response effort. Requests for assistance from Mexico are being handled by the Agency for International Development, and to date FEMA has not been asked to provide support.

However, in recognition of the earthquake hazard in the common border areas of San Diego, Tijuana, and Calexico-Mexicali, the United States and Mexico have developed a joint project to reduce the effects of earthquakes in these areas. FEMA is directing and coordinating this Nation's participation in this joint effort. A 5-year work plan was agreed upon this past year by both governments, and initial tasks have begun.

However, with the help of FEMA funding appropriated under the national plan, the National Academy of Sciences Committee on Natural Disasters has dispatched an initial team of experts to Mexico to obtain perishable data and provide firsthand observations of what occurred.

In addition, a joint 5 person NBS/USGS team traveled to Mexico City to investigate, in a reconnaissance fashion, building damage and strong motion records. Subsequent teams are expected to follow.

The information obtained from these teams and others will undoubtedly provide extremely valuable information upon which to assess our current activities under the national plan, and if necessary, change our planning for the future.

While it is difficult at this time to supply the subcommittee with any definitive information based upon actual experience, the widespread media coverage of the event allows me to offer two general conclusions. First, the Mexican earthquake experience appears to be consistent with and reinforces planning scenarios developed for postulated earthquakes in high risk areas of this Nation.

The magnitude and complexity of the post-earthquake response environment in Mexico in terms of life loss, injury, property damage, and secondary impacts (such as fire resulting from ruptured gas lines), are considerations for which Federal, State, and local governments are planning in this Nation's high seismic risk areas.

Second, the partial or total collapse of structures is the main cause of earthquake deaths and injuries. As has been vividly demonstrated, the earthquake in Mexico was no exception.

This fact unequivocally reinforces the need to incorporate seismic resistant design provisions into State and local building codes throughout the high seismic risk areas of the country. The sooner this is accomplished, the sooner the earthquake threat within this Nation will be reduced.

Approximately one-third of FEMA's appropriation under the national plan is devoted to the development (and dissemination to design professionals, code groups, and State and local officials) of seismic resistant design provisions applicable to new buildings, existing hazardous buildings, and to lifelines.

Unfortunately, this is a difficult and time-consuming task, which is dependent, among other things, on the results of research and the support of all sectors of society.

In summary, the seismic activity which so tragically impacted Mexico City is providing us with a living laboratory of data on

earthquake hazards and the means that can be taken to effectively address them.

FEMA is eagerly awaiting the reports of the onscene assessment teams which will hopefully provide us with valuable insights on how the Mexican preparedness and response planning that was in place at the time of the earthquake actually performed.

For example, was the structured direction and control element of the Mexican preparedness plan effective? What unanticipated logistical support needs were encountered? Was the organization of the mass medical care systems adequate? What communication problems were encountered? What was the impediment to search and rescue efforts?

Answers to these and many other similar questions will assist us in critically evaluating our own preparedness and response planning activities.

FEMA is also interested in seeking to understand the forces and structural characteristics which caused building and lifeline failure. For example, what types of buildings tended to fail, and why? Did the city's building codes have an impact on reducing losses? What code enforcement measures had been taken? How does the geologic understructure relate to the apparent building-to-building and block-to-block devastation?

It is an unfortunate truth that the tragedy of our sister nation may well allow us to improve our own efforts in reducing the hazards of earthquakes. However, it will be ironic and a real tragedy here if we do not learn from that experience.

[The attachments referred to follow:]

ATTACHMENT #1

THE FIVE PROGRAM ELEMENTS AND RESPONSIBLE AGENCIES

Hazards - Delineation and Assessment	1	Regional Monitoring and Earthquake Potential	USGS
	2	Earthquake Hazards Assessments-National and Regional	
	3	Postdisaster Mitigation Studies	FEMA

Earthquake Prediction Research	1	Precursor Evaluation and Prediction Methodology	USGS
	2	Earthquake Prediction Experiments	
	3	Theoretical, Laboratory, and Fault Zone Studies	
	4	Induced Seismicity	

Seismic Design & Engineering Research	1	Development of Design Practices and Manuals	FEMA/ NBS
	2	Fundamental and Applied Research	NSF
	3	Engineering Seismology	USGS
	4	Modernization of Existing Research Facilities	NSF
	5	National Earthquake Experimental Capability	FEMA

Preparedness Planning and Hazard Awareness	1	Earthquake Hazard Mitigation Strategies	FEMA
	2	Federal Response Planning	
	3	State and Local Preparedness Planning	
	4	Multi-Hazard Preparedness Planning	
	5	Earthquake Education and Information Transfer	
	6	Societal Response Research	NSF

Fundamental Seismological Studies	1	Implications of Plate Tectonics	NSF
	2	The Earthquake Process	
	3	Earthquake Data and Information Services	USGS

ATTACHMENT NO. 2.—FEMA RESPONSIBILITIES

1. NEHRP Leadership Role/Interagency Coordination.
2. Seismic Design and Construction Standards
3. State and Local Hazards Reduction Programs
4. Federal Response Planning
5. Mitigation and Multihazard Preparedness Planning
6. Earthquake Education and Information Transfer

[The following information was subsequently received for the record:]

QUESTIONS OF SENATOR GORTON AND THE ANSWERS

Question. What is the Federal Government doing to ensure that Federal facilities meet seismic-resistant building standards?

Answer. The Interagency Committee on Seismic Safety in Construction (ICSSC), funded by FEMA and chaired by NBS for FEMA, is taking two major actions in this regard. First, it has updated a seismic building standard for new buildings that was first formulated in 1981. The ICSSC member agencies are now balloting this updated document and a new version, reflecting the results of this consensus process, is expected to be ready during the current fiscal year. The new version will establish a minimum level of seismic safety for new Federal buildings, while setting an example of seismic hazards mitigation for the private sector to emulate. Second, the ICSSC has prepared and submitted for balloting to members agencies a draft Executive Order on the subject of seismic-resistant Federal buildings. A number of policy questions, including the exact scope of the draft Order, need still to be resolved before the draft is forwarded to OMB for its consideration.

Question. Is legislative action by Congress needed to ensure that Federal facilities will meet seismic-resistant building standards?

Answer. In view of the two major ongoing initiatives described in the previous answer, FEMA believes that legislative action is not needed at present.

Question. We've heard a lot of discussion about the type of losses that could be expected if a major earthquake were to strike one of our major metropolitan areas. Do you have any figures as to what we could expect in terms of insurable losses?

Answer. A study commissioned by the California Department of Insurance examined the question of probable maximum losses from an earthquake with an 8.25 magnitude. In 1983, the probable maximum loss in San Francisco would be $3.9 billion; in Los Angeles, $5.4 billion. These figures, which are rising continuously, assume that 5 to 7 percent of homes have earthquake insurance with a 5 percent deductible. These figures do not include losses from associated risks: workers compensation, automobile, life and health, fire following an earthquake, and exposure from landslides or tsunamis.

If the deductible were eliminated which could happen as a result of court rulings, i.e. concurrent causation, and every homeowner purchased earthquake insurance, the probable maximum loss would rise dramatically. In San Francisco, the losses would approach $27 billion; in Los Angeles, $29 billion. Taking into account exposure from associated risks, these figures probably would double: $50 billion in San Francisco, $60 billion in Los Angeles.

Question. You noted in your testimony that relatively few residential and small business owners purchase earthquake insurance. Have you been able to determine the reason for this level of market penetration?

Answer. In 1980, a study was performed for the Federal Insurance Administration. It showed that homeowners and small business owners assign low priority to the purchase of earthquake insurance because earthquakes are low frequency events. This makes the risk seem minimal.

Other reasons stated for low penetration included: Disaster relief programs act as disincentives for the purchase of earthquake insurance; many residential and small business owners are unaware of the availability of earthquake insurance; and earthquake insurance is not required by lending institutions to protect mortgages.

Question. I've heard some suggestion that if the Federal government were to get involved in earthquake insurance that we ought to simply use the National Flood Insurance Program as our example, and adopt a program similar to what we currently provide for flood insurance. I notice that you haven't mentioned that in your testimony. Could you please briefly describe your thoughts on that suggestion?

Answer. I do not envision the solution to the earthquake insurance problem to be similar to the National Flood Insurance Program (NFIP). Eighty percent of all presidentially declared disasters are flood related. The program has a high frequency and also has relatively high annual costs. The NFIP has an extensive, costly mapping program and stringent Federal building requirements as integral components, Earthquakes, as previously mentioned, are low frequency events. The Federal Government should not impose, and the taxpayers would not accept, the same type of building standards and costs associated with the NFIP.

To begin addressing this increasing problem, I would envision a partnership between the private and public sector similar to the NFIP's Write-Your-Own program initiated two years ago, but one meeting the other criteria I addressed in my testi-

mony. I would be opposed to incorporating extensive risk mapping because the associated costs are unjustifiable in light of the relatively low frequency of earthquakes when compared with other insurance risks. Risk assessment and low reduction activities can and should be handled by simple insurance rating formulas.

Question. Do you believe that this is the sort of issue that could be handled at the state level where insurance is currently regulated, or do you believe that federal support is required?

Answer. To his credit, California Insurance Commissioner Bruce Bunner is attempting to work with the insurance industry to construct a State solution to the problem of earthquake insurance. I encourage his efforts, and if he is successful, that would be the approach to be taken.

Unfortunately, this problem may prove to be more significant than the cyclical types of cost or availability programs which from time to time come before the Congress. The problems traditionally have been solved either by the private sector or through State regulation. Earthquake insurance may be one risk that calls for cooperation of all parties and innovative solutions.

Senator GORTON. Doctor, thank you very much.

Dr. Peck.

Dr. PECK. Yes. Good morning, Senator. I am Dallas Peck, Director of the U.S. Geological Survey, and I welcome the opportunity to present a preliminary report on the geological aspects of the recent tragic earthquake in Mexico.

I am submitting a written statement for the record.

Senator GORTON. It will be included in the record.

Dr. PECK. Thank you. And I have comments on a few posters that we have prepared.

My comments have benefited from the field report of Dr. Thomas Hanks, one of our scientists who is a member of the team led by the National Bureau of Standards that was in Mexico City last week.

Dr. Hanks is in the audience here in the first row. He came here directly from Mexico City.

I am accompanied by Dr. John Filson, Chief of our Office of Earthquake, Volcanoes, and Engineering. I think it would work best, Mr. Chairman, if I just come up here and point out the salient features on charts that our marvelous staff has prepared.

This first map, a view of central Mexico, illustrates the situation. Here is the magnitude 8.1 earthquake that occurred at 7:18 a.m. on September 19. The severe damage occurred as far away as Mexico City, and the earthquake was felt in El Paso and Houston, TX.

The earthquake filled the Michoacan seismic gap, an area very low in historic seismicity. There was a 7.3 earthquake in 1981, but it apparently did not release the seismic strain that had accumulated in that gap.

Aftershocks occurred along the coast in an area 200 to 300 kilometers long—150 to 200 miles long. There are very few aftershocks greater than magnitude 5. That was surprising. There was a magnitude 7.5 event on September 20 that itself caused a fair bit of damage.

As I said, the earthquake caused severe damage more than 200 miles away. That is as if an earthquake occurred in St. Louis and knocked down buildings in Kansas City.

Senator GORTON. Doctor, why was it that the damage was so heavily concentrated in Mexico City rather than the epicenter?

Dr. PECK. That is because of the local geological situation. Which is the point of my testimony. We will get to that, particularly in some of the later posters. Good question.

The crust of the earth is broken into about a dozen plates that are moving slowly under forces generated by deep forces in the earth. One of those is the Cocos plate, which is shifting under the North American plate at about 2½ inches a year. This is illustrated here. This shows the Cocos plate coming out from a spreading zone and diving under the west coast of Mexico. It moves at about 2½ inches a year.

The earthquake was at a shallow depth of about 20 miles or less than 20 miles, right along the boundary between the Cocos plate and the North American plate. The point is that it is moving 2½ inches every year, and that the pressure builds up over a period of time.

There is enormous strain building up, and the release of that strain and the slip along the fault causes the earthquake. The seismic waves radiate from the focus, and it was those waves that hit Mexico City and caused the damage.

Now, under normal situations you wouldn't expect that sort of damage at a site 200 miles away from the epicenter. However, there is a thick column of alluvial unconsolidated sediments under Mexico City, and they amplified the signal, and that was why there is as much damage.

The next poster illustrates the point, and that is that earthquake ground motion is amplified by soft sediments both in Mexico City and in San Francisco. We have done a very detailed study of the ground amplification of seismic waves in San Francisco using distant earthquakes and using underground nuclear explosions in southern Nevada at the test site.

This poster shows, for example, the amplification. This shows the trace of a seismogram, the shaking from an individual underground nuclear explosion. This is what it looks like on a hard rock. You can see very, very low amplitude. This shows it on a semiconsolidated sediment, Tertiary sediments.

This shows what it is like on the bay muds.

Senator GORTON. And that is the red?

Dr. PECK. And that is the red. We have done a very detailed study measuring amplification at many sites around the Bay and relating that to geologic mapping of the material. That was published just a few years ago in this *Studies for Seismic Zonation of the San Francisco Bay Region.*

Senator GORTON. Now, does that indicate, Doctor, that in the city of San Francisco itself the same degree of earthquake would have a widely differing impact in various parts of the city?

Dr. PECK. That is right, and during the 1906 earthquake the damage was far more intense on the bay muds, the saturated bay muds and artificial fill.

Incidentally, we have done a similar study in the Los Angeles region, and we have a meeting November 12 and 13 with city planners, our colleagues in FEMA, other organizations, and the academic community to lay out this sort of a zonation for the Los Angeles basin. We have a meeting late in October in Seattle to discuss this and other aspects of the seismicity in the Puget Sound region.

This is a map of downtown Mexico City showing the geology. Mexico City is a basin like the basins in the Great Basin in Nevada and Utah. It was formed by faulting about 30 million years ago, and filled with a thick section, 10,000 to 15,000 feet of sediment.

Then about 3 million years ago there were volcanic eruptions at the south part that blocked the drainage. The drainage went from north to south. It blocked the drainage down here so that the valley around Mexico City filled up with a lake.

In that lake were deposited muds and ash from the erupting volcano, so there is a thickness of about 150 feet of water-saturated sediment that covered the thick semiconsolidated sediments in that valley, and it was amplification of the seismic waves, particularly in that 150 feet of saturated mud, that caused the problem.

The situation is that, in the soft sediment, seismic waves are not only amplified, as shown here, but the period of the energy shifted. It shifted to longer periods, so that the period was about 1 or 2 seconds from the seismic waves in Mexico City, and that is just about the same period as the resonance period of buildings that are 5 to 15 stories high.

So, that caused part of the problem. Another part of the problem is that in the soft muds of the Mexico City region, the buildings sink, as they sink in parts of San Francisco, and some of them sank very quickly as a result of shaking of the ground during the earthquake, and that also caused part of the problem.

That concludes my testimony.

[The statement follows:]

STATEMENT OF DR. DALLAS L. PECK, DIRECTOR, U.S. GEOLOGICAL SURVEY

Agency Mission

The U.S. Geological Survey (USGS) is a major participant in the National Earthquake Hazards Reduction Program. The goal of the USGS participation in this program is to mitigate earthquake losses that can occur in many parts of the United States by providing research, evaluations, and data for earthquake warnings, hazards assessments, engineering design, and emergency preparedness decisions. Specific objectives of the USGS program are: (a) to evaluate the earthquake potential of the seismically active areas of the United States; (b) to provide assessments of earthquake hazards in developed regions; (c) to predict damaging earthquakes; (d) to provide data and information on earthquake occurrences to the public and scientific community; and (e) to provide data and studies of strong earthquake shaking for use in earthquake-resistant design and construction. The September 19, 1985, Mexico earthquake, with all its tragic consequences, provides lessons and experience to help us further our work toward all of these objectives. I would like to discuss our current understanding of the Mexico earthquake and its effects. Further study of this event and its consequences will be required to develop a more complete and accurate picture.

Seismological Aspects

On Thursday, September 19, 1985, an earthquake of magnitude 8.1 struck the western coast of Mexico near Playa Azul in the State of Michoacan. The earthquake caused widespread damage in central Mexico, particularly severe in Mexico City, and was felt as far north as El Paso and Houston, Texas.

For an earthquake of this size, there were few large aftershocks immediately following the main shock; none above magnitude 5. Then on Friday evening, September 20, 1985, a second major earthquake of magnitude 7.5 occurred in the region. The epicenter of this second event was located about 100 km southeast of the main shock; it is considered an aftershock of the larger earthquake. The aftershocks following the 7.5 event have remained small; however, further damaging earthquakes in this sequence in the magnitude 6-7 range cannot be ruled out. The length of the sequence is likely to be measured in months.

Reports from the field indicate that the distribution of aftershocks covers a region about 300 km long and 150 km wide. Since the zone of aftershocks is usually taken to represent the dimensions of the fault break in an earthquake, this event represents a major rupture of the plate boundary that occurs just off the western coast of Mexico.

Tectonic Setting

These earthquakes occurred in a narrow seismic zone that runs some 2500 km along the western coast of Central America from Panama to central Mexico west of Puerto Vallarta. This zone of intense seismicity is formed by the collision of the Cocos Plate to the southwest and the North American Plate to the northeast. The crust and upper mantle of the Earth are segmented into about a dozen sections or plates that slowly drift away from zones of crustal spreading found along mid-ocean ridges. About 90 percent of the Earth's seismicity is found along plate boundaries, either along mid-ocean spreading zones or where plates collide.

In the vicinity of the recent Mexico earthquakes the Cocos and North American plates are converging at a rate of about 6 cm per year. (In human terms, this is about the rate at which fingernails grow). Along the line of convergence the Cocos plate dips beneath or is overridden by the North American plate giving rise to earthquakes along the coast and volcanoes inland in central Mexico.

The mechanics of colliding plates are complex. The relative motion between the rocks in the two plates can be accommodated as continuous aseismic (non-earthquake-generating) slip in the fault zones that have formed at the plate boundaries. In other cases the faults do not slip continuously, but accommodate the relative plate motion through elastic deformation in the nearby rock. These cases give rise to earthquakes. The ability of the rock at the plate boundary to absorb the plate motion elastically through strain accumulation is limited. When this elastic limit is exceeded the rock or fault breaks instantaneously and an earthquake results. In most fault zones continuous aseismic slip and earthquakes occur. The degree of each depends upon the details of the fault geometry and its mechanical properties. These properties also dictate the types of earthquakes that occur in a given zone of a plate boundary. The elastic strain may be released by numerous smaller earthquakes with fault breaks measured in tens of kilometers or by infrequent major events with rupture zones measured in hundreds of kilometers.

Given that plate motion is constant over the long term and that individual zones of a major plate boundary have a characteristic style or mechanism of accommodating plate motion, statements about regional earthquake potential are possible and are now commonly made. These statements are based on the general concepts given above and the past record of earthquakes in the region. If a particular zone is overdue for its characteristic earthquake, or an earthquake has never occurred within it, a "seismic gap" is said to exist there.

Prior Forecasts

Mexican and United States scientists have studied the characteristics of the various seismic zones of the western coast of Central America for several years and have been able to establish patterns or cycles in some areas. One study has concluded that prior to 1981 no large earthquake (greater than magnitude 7) had occurred in this century, and perhaps since 1800, in the zone of the recent earthquake. There is some question concerning the location of a magnitude 7.9 event in June 1911 that might have occurred in this zone. Nevertheless, the region has been identified as the "Michoacan seismic gap" in recent literature. The length of this gap was about 150 km. Adjacent seismic zones seem to have seismic cycles that give rise to earthquakes of about magnitude 7.5 every 35 years or so. It was suggested that either the Michoacan gap was aseismic, the plate motion being accommodated by continuous slip, or, alternatively, that the recurrence time of earthquakes in this zone was much greater than those in adjacent zones. A corollary to the latter alternative is that the more infrequent earthquakes will be larger than those in adjacent zones.

In October 1981, a magnitude 7.3 earthquake occurred in the eastern half of the Michoacan gap, dispelling the notion that the region is incapable of generating large earthquakes. Following the 1981 Michoacan event the aftershocks spread over only about one-third of the gap, leading to the conclusion that the gap had not been "filled." The questions of whether a magnitude 7.3 was the characteristic earthquake for the region or whether the region was capable of producing a larger earthquake, one that would fill the gap, continue to be debated.

Although detailed analyses of the recent events have just begun, there is little doubt now that they released the accumulated elastic strain in the Michoacan zone, filled the gap, and may have broken into adjacent zones. It now seems important to revise priorities and reexamine the entire region of seismicity off the western coast of Mexico and to revise earthquake potential estimates pertaining to it.

Earthquake Effects

The human tragedy caused by the Mexican earthquake has been widely reported in the press and on television in the United States and will not be repeated here. The most significant hazard mitigation lessons of the earthquake are found in studying what happened in Mexico City and why.

Mexico City is notorious for being shaken by earthquakes, many of which have epicenters 300-500 km away along the plate collision zone discussed above. For example, in a small booklet entitled Earthquakes in Mexico City we find this quote: "While local officials were awaiting the entrance into the City of the leader of the revolution on June 7, 1911, there was a major earthquake at 4:26 AM. The local barracks of San Cosme were demolished as well as other buildings and walls in different parts of the city. There were 39 badly wounded and 49 deaths. Other earthquakes were subsequently felt and church bells rang by themselves. The earthquake of June 7, 1911, was the most intense since that of 1845." This describes the earthquake in 1911 that may have been located in the Michoacan area near the recent earthquakes. The book covers the period from 1729-1961 during which there were 13 instances of earthquake damage in Mexico City, an average of about once every 18 years.

The characteristics of earthquake shaking at any location are influenced by a number of factors including: the magnitude of the earthquake, the distance of the site from the source of energy release, the geologic properties of the rock that transmit the seismic waves from the source to the site, the source mechanism of the earthquake, seismic wave interference or focussing effects related to broad geologic structures near the site, and local soil and geologic conditions at the site. Damage resulting from the ground shaking, of course, depends upon the design and construction characteristics of buildings at the site. Since Mexico City has a long history of being particularly senstive to earthquake shaking and was more heavily damaged than cities and towns closer to the recent earthquake, local geology and soil conditions must have played an important role in the distribution of recent damage as they have in the past.

Mexico City lies in a broad basin formed by block faulting of a uplifted plateau about 30 million years ago. About 3 million years ago volcanism in the region was renewed and lava flows formed a dam across this valley just south of Mexico City. This dam resulted in the formation of a large lake that slowly began to fill with silt, clay, and ash from nearby volcanoes. Changes in the climate during this period led to oscillations in the level of the lake. Remnants of ancient beaches indicate that about 7,000 years ago the level of the lake was about 160 meters above the main level of the present city. Indian civilizations developed around the lake and, indeed, the Aztecs built their capital on an island in the lake connected to the shore by causeways. The Spaniards, after conquering the Aztecs, destroyed the causeways. They soon learned the causeways played an important role in flood control for the Aztec city. To solve the flood problem, canals were built to drain the lake to the north. As the water level dropped, several small lakes were formed from the single lake and portions of the old lake bed were exposed around the ancient Aztec capital. This lake bed has been used for the expansion of Mexico City. Today, much of the City rests on lake deposits made up of silty, volcanic clays and sands with thicknesses of 50 meters or greater. These lake deposits overlay other, older sedimentary sequences with thicknesses up to 2,000 meters. The lake clays are very compressible and have a high-water content. These characteristics, along with ground water pumping, have led to the sinking of some buildings in Mexico City and the requirement that large structures be placed on sunken piles.

When unconsolidated material underlies a site, the seismic shaking is modified from what it would have been on competent rock. The amplitude of the earthquake ground shaking on unconsolidated material, relative to that on hard rock, can be increased in some frequency ranges and decreased in others. The degree of amplification of the ground motion is a function of the seismic wave velocities, the density and other mechanical properties of the material, its thickness and water content, and irregularities in the surface of the bedrock. The general trend is for unconsolidated sediments to increase the amplitude of ground shaking at lower frequencies relative to competent sites. As the high amplitude ground shaking shifts toward lower frequencies (longer periods, say .5 - 3 seconds) it shifts toward the resonant frequencies of higher buildings. If the ground is shaking at the natural or resonant frequency of a structure, severe damage and collapse are more likely. Energy is pumped into the base of the building at the frequency the building will naturally vibrate because of its design. This causes the ground shaking to be amplified in the building.

Early reports from Mexico City indicate that of the total of 500-600 collapsed structures, many of them were in the 5-15 story range, with relatively less damage in lower and taller buildings. This may indicate that the vibrations in the underlying sediments were in tune with the natural frequencies of these mid-level buildings. Observation of variations in damage in identically designed nearby structures indicates variable ground motion over short distances, or variable construction quality, or both. These early reports indicate that complete foundation failure may be involved in about 10 percent of the collapses.

Although much more research and study of this earthquake need to be carried out, the causes of the concentration of destruction in Mexico City are probably due to one or more of the following factors:

- o amplification of ground shaking at lower frequencies due the unconsolidated sediments on which much of the City is built,
- o weakened structures due to settlement of foundations, and
- o coincidence of the frequency of maximum ground shaking and building resonances.

It is estimated that over 100 recordings of strong shaking, either of the ground or in structures, will be obtained from instruments throughout Mexico. This data will be invaluable in carrying out further research.

Agency Response

The Mexico earthquake was reported to various Federal agencies and news services by the USGS's National Earthquake Information Center. This was done by telegram within an hour of the event, following routine procedures. During the next few days USGS employees at the National Earthquake Information Center and other locations responded to numerous requests by Federal and foreign officials, the press, and the public for information on the event and on earthquakes in general. Information gathering was hampered severely by lack of telephone communication with Mexico City.

Two USGS scientists were part of a study team to Mexico City led by the National Bureau of Standards and supported by the Office of Foreign Disaster Assistance of the Agency for International Development. The USGS scientists were to meet with counterparts at the University of Mexico to discuss the earthquake and its effects. The USGS received no request for assistance from the Mexican government.

Relation to Current USGS Program

The Mexico City experience reinforces the requirement for the study and understanding of local geologic conditions on earthquake ground shaking and the application of this understanding to construction practices and land use. The USGS has carried out studies of ground shaking amplification in San Francisco and Los Angeles and is pursuing similar work in the Salt Lake City and Anchorage areas. Experience in the Mexico City earthquake can be used to refine and accelerate these studies. It is important, if possible, to pursue and apply techniques that allow assessment of this problem without expensive drilling at a particular site or without waiting for the site to be shaken by an earthquake.

The recent event clarifies the tectonic processes off the coast of Mexico and will provide valuable data for the future assessment of long term seismic risk from this area. In view of the seismic gap approach to the assessment of risk, it points to the care that must be taken in assigning seismic risk to a zone of a seismic region when that zone has no record of large earthquakes to date.

Finally, this earthquake points to the importance of a multi-faceted approach to earthquake hazard mitigation. Earthquake prediction, detailed earthquake hazards assessments, seismic-resistant design, engineering, and construction practices, and earthquake emergency planning and response all play an important role in saving lives and reducing property losses. From the study of the recent Mexico City earthquake we can learn how these various elements can be better developed and applied in the future in the United States and elsewhere.

Senator GORTON. Thank you very, very much, Doctor. That was tremendously enlightening to us.

Dr. Suh is next.

Dr. SUH. Thank you, Mr. Chairman and members of the subcommittee, and thank you for giving the National Science Foundation the opportunity to provide testimony on the Mexican earthquake to this subcommittee.

Mr. Chairman, in preparation of this hearing, we prepared written testimony which I would like to submit for the record.

Senator GORTON. It will be included in the record in full.

Dr. SUH. My oral testimony will be brief, covering only the relevant information.

I would like first to outline some of the activities we have undertaken at the National Science Foundation in response to the Mexican earthquake. First, we sent a quick response team to Mexico City through the Earthquake Engineering Research Institute and the National Academy of Engineering. They have provided us with some preliminary information.

Second, we have sent several additional individuals under existing grants to Mexico to collect highly specialized and perishable information related to the earthquake. Example areas are fire consequences and performance of health facilities and activities.

Third, we have made an offer through the Department of State to the Government of Mexico to provide engineering support through our research community.

Fourth, we have established through the Earthquake Engineering Research Institute and the National Academy of Engineering a reconnaissance team briefing meeting to be held on October 14 to decide on the followup actions required to maximize learning from the earthquake.

Fifth, we had in place, through existing cooperative research projects, a strong motion network near the earthquake epicenter. The earthquake record data appear to be of excellent quality. We have also been involved in cooperative activities related to strong ground motion studies in the Mexico City Basin.

I have a few slides which I would like to show to illustrate some of the things we have done. In view of the earlier testimony, I will be brief.

The first slide shows that Mexico is not far away from the United States, and so we are neighbors. In view of the earlier testimony, I will not go into details, but as the slide illustrates, the real issue here is the the severity of the damage 250 miles away from the epicenter.

The next slide shows the earthquake risk region along the California coast. One of the interesting things is that the nature of the faults along the western coast of Mexico is quite different from the nature of the faults in California. The faults and geologic structure are similar to that near the coastline of the States of Washington and Oregon.

Senator GORTON. I am sorry. Would you repeat that? You were saying the California situation is different from Mexico, in regard to the type of fault, but that the fault in Mexico is like that in Puget Sound?

Dr. SUH. Yes. The Mexican earthquake occurred along a type of plate boundary known as a subduction zone, that is a type of interaction whereby one giant lithospheric plate thrusts beneath another. That kind of situation exists along the coast of the States of Washington and Oregon.

Senator GORTON. Senator Gore referred to the New Madrid situation in the Midwest. Is that a third and different kind of fault?

Dr. SUH. Senator, I am not a specialist on this topic. It is my understanding that the New Madrid situation is not a plate boundary geometry but rather an interior plate situation. I can have my specialists answer further questions on this topic if you wish.

The slide shows that a fault extends all the way along where the plates meet. Again I emphasize that the geologic structure setting existing along the coast of the States of Washington, Oregon, and Alaska is similar to that which exists along the western coast of Mexico.

The next slide shows a reinforced concrete building. This building was somewhere between 8 and 14 stories tall. Most of the buildings that collapsed in Mexico City were of reinforced concrete construction. It should be noted that these 8- to 14-stories-tall buildings had a period of about 2 seconds, and that the earthquake motion, as we will show later, had a maximum acceleration at a period of 2 seconds. Therefore, the buildings, which had a natural resonant period of 2 seconds, were coupled with the earthquake motion and hence were the ones which collapsed.

Senator GORE. When you say period, that is the length of time between the wave peaks?

Dr. SUH. That is right; period is the inverse of frequency. The next slide shows a steel building. It shows that even steel buildings can collapse. I understand that most of the buildings that collapsed were of reinforced concrete construction.

This is another view of the same collapsed steel structure.

Senator GORTON. Excuse me. Would you go back to the previous slide, back up one?

Now, there you are illustrating, I take it, that the collapsed building in the foreground was a steel frame building?

Dr. SUH. Yes.

Senator GORTON. There is one building in the background which looks totally intact. Is that because of the height of this resonance that you are speaking about? Why would you have that striking a difference in two adjacent buildings?

Dr. SUH. Senator, your perception of the situation is important. In fact, both buildings are 21-story-tall steel buildings. One building collapsed, and the other did not. The question is, Why? We do not know all the answers. However, this indicates that during an earthquake different responses can occur over a few hundred feet of distance.

This is one of the topics that requires research attention. Why do those special variations occur and why do two similar steel structures located next to each other perform differently during an earthquake? These are research issues, and we do not have all the answers.

Again, this is another view of the same building and it shows the degree of damage that can occur. The next slide is a collapsed

apartment building of the reinforced concrete construction. I understand that about 1,000 people died in this building. Two of three wings of the apartment building collapsed.

The next slide is another view of the same collapsed reinforced concrete building. The next slide is an overall view of Mexico City looking west from the U.S. Embassy. You can see there are many, many buildings still standing in the same city where many buildings were destroyed. Apparently this is the case because these buildings and the soil conditions are quite different in this part of Mexico City.

So, again, it is necessary to really understand the details of the soil conditions and the interaction between the earthquake and the resonant conditions of the building. In the Mexico City case, this complex interaction apparently caused some of the disasters we have described and have seen here today.

You would expect some of the very poorly built buildings to collapse during the earthquake. The next slide shows what appears to be poorly constructed masonry buildings, and yet they stood up. The reason we believe they stood up is because the natural frequency of these masonry buildings is much higher than the predominant ground motion. Therefore, they were not in resonance with the ground motion and withstood the ground motion and remained intact.

The next slide shows the effects of the breakage of an aqueduct leading to Mexico City. Water pressure was low and there was a shortage of water. The next slide shows a seismic record that was obtained on firm ground during the earthquake in Mexico City. The acceleration that was recorded here is only about 4 percent of acceleration due to gravity.

So, on the firm ground, the acceleration is only about 4 percent, whereas the next slide shows that on the soft ground, because of the amplification effect, higher acceleration is recorded. This acceleration is about 18 percent of the acceleration due to gravity, or 4 to 5 times as high as that recorded on firm ground.

If the buildings described earlier were located in these soft soil areas, this is where we would expect the major damage to occur. The next slide is replotting the earlier response in terms of what we call a response spectrum. This shows acceleration plotted versus period, and it indicates that the maximum response occurred at about 2 seconds There are several smaller peaks, but the maximum acceleration occurred at about a 2-second period which is the natural period of the buildings which collapsed.

I understand that in California similar buildings with similar heights would have a natural period of about 1 to 1.5 seconds because of different construction techniques. A current National Science Foundation sponsored research program involved placement of instruments along the Mexican coastline. We expect to obtain rich data which will tell us a great deal about the characteristics of the ground motion near the epicenter. This will be very valuable data and information which will influence our Earthquake Hazard Mitigation Research Program. We do not have all the data yet because these sites are quite remote.

The next slide shows that even the foundation was uprooted and pulled out of the ground. This illustrates failure of a foundational system. The top seven stories of the building also collapsed.

This slide is another view of the tragic damage. This shows the really human tragedy associated with this kind of earthquake. It was apparent that they did not have supplement means of rescuing people in a short period of time. They did not have adequate means of cutting and destroying the concrete to permit rescuing the people. I believe this is an area in which we need to do more research in the future.

In the next slide you can see the fingers of a woman trapped under the collapsed building.

The next slide shows a structure under construction at the University of California at San Diego under the sponsorship of the National Science Foundation. This laboratory will be used to study how masonry buildings and bridges will react to earthquakes. This is under construction and will be completed some time in June.

We show this to you as an example of an NSF program related to earthquake hazard mitigation. We are very serious about mitigation of earthquake hazards.

This is the end of the slides, and I have a few more statements to make.

As you have seen from the slides, the critical question is why such poor performance occurred to so many structures in a known earthquake zone. Part of the answer may be due to old existing buildings which were constructed without the benefit of current knowledge and practice. However, this would not explain the behavior of newer structures constructed under the current code.

Several features of this earthquake were quite different, and were vitally important in comparing—the actual building performance to what had previously been predicted.

First, the absolute intensity of motion developed on the old lake bed were much greater than had been predicted. Second, the duration of strong shaking was much longer than is normally the case with a strong earthquake, which resulted in greater structural damage.

Many lessons can be learned from the Mexico earthquake which would be of benefit to providing greater earthquake safety in the United States. The chain of events resulting in many collapsed structures with trapped persons has shown there is a need for an improved knowledge base for locating and rescuing people.

This area of research has not received high priority in the past in comparison with other needs. However, it appears that research is needed in this area. For example, it may be possible to develop techniques to selectively disintegrate concrete and other materials in order to free trapped people.

Some of the problems experienced in the Mexico earthquake are ones that have been under study in our National Science Foundation research programs. It is important to continue these. This disaster presents us with a major opportunity to learn and prevent a similar disaster from happening in the United States.

Field studies needed to learn from the Mexican earthquake will be costly to complete. We will do what we can with our limited resources to obtain data and information to maximize our learning

from this most unfortunate laboratory experiment that nature has provided to us.

Thank you.

[The statement follows:]

STATEMENT OF DR. NAM P. SUH, ASSISTANT DIRECTOR FOR ENGINEERING, NATIONAL SCIENCE FOUNDATION

Mr. Chairman and Members of the Subcommittee, thank you for giving the Natinal Science Foundation the opportunity to provide testimony on the Mexican earthquake to the Science, Technology and Space Subcommittee of the Senate Committee on Commerce, Science, and Transportation. This opportunity is especially important to the National Science Foundation because of our significant participation in the National Earthquake Hazards Reduction Program and our desire to capture valuable information and learn as much as possible from this earthquake.

First let me provide a brief overview of the National Science Foundation's earthquake engineering and science research program. Our research program is divided into five categories in two different Directorate as follows:

ENGINEERING DIRECTORATE

Siting and geotechnical systems

This research addresses the fundamental engineering issues related to earthquake ground shaking and describes earhquake interactions on geologic structures including surface and subsurface soil and rock systems. The primary research areas are strong ground motion, stability of geotechnical systems, tsunami systems engineering and lifeline systems.

Structural systems

The purpose of this research is to develop the capabilities to predict the behavior of structures during earthquakes, establish practical guidelines and methods for engineering design against earthquake loading, and provide economically feasible methods to strengthen existing hazardous structures. Some specific research areas are dynamic non-linear systems, new and reliable desirn methodologies, computer simulation, knowledge based computer systems, damage assessment methodologies and lifeline systems.

Architectural and mechanical systems

Research is conducted on architectural and mechanical components and systems whose failure during an earthquake could result in serious loss of life, damage, economic losses and disruption. Examples are architectural and mechanical components in buildings such as glass and exterior cladding, elevators, building mechanical systems, power generation and transmission facilities, building contents, communication systems and masonry structures in which architectural and structural systems may be integral. Motion mitigation systems such as dampers, active control systems and base isolation devices are also considered.

Earthquake system integration

This category of research supports research and related activities for the integration of knowledge-producing and knowledge-using systems. Key areas of research include earthquake mitigation planning; earthquake preparedness planning; impacts, recovery and reconstruction; and technology delivery.

ASTRONOMICAL, ATMOSPHERIC, EARTH, AND OCEAN SCIENCES DIRECTORATE

Fundamental earth sciences

This research develops the fundamental understanding of the tectonic conditions necessary for earthquake occurrences and provides a framework for earthquake prediction and hazard evaluation. Areas of research include plate tectonics, crustal structure, seismology, crustal deformation, and volcanism and landslides related to earthquakes.

Now let me tell you about a few activities currently supported by the National Science Foundation—Earthquake Hazard Mitigation (EHM) program related to the Mexico earthquake.

We are supporting through our existing programs quick response teams assembled by the Earthquake Engineering Research Institute (EERI) and the National

Academy of Engineering (NAE) which have gone to the earthquake area to document highly perishable engineering information. They will be shortly reporting back on possible research actions following their reconnaissance work.

We have sent several additional individuals under existing grants to Mexico to collect highly specialized perishable information related to the earthquake. Example areas are fire consequences and performance of health facilities and activities.

We have made an offer, through the Department of State, to the government of Mexico to provide engineering support through our research community.

We have established through EERI and NAE a reconnaissance team briefing meeting on October 15 to decide on the follow-up actions required to maximize learning from the earthquake.

We had in place, through existing cooperative research projects, a strong-motion network near the earthquake epicenter. The earthquake record data appear to be of excellent quality. We have also been involved in cooperative activities related to strong-ground motion studies in the Mexico City Basin.

We are supporting the development of a new Global Digital Seismic Network with real time satellite transmission of wide-band digital seismic data. This new Network will eventually give us the capability to determine the size, precise location, and source mechanism of an earthquake within minutes of the event. This information will be most helpful in timely determination of tsunami potential, expected aftershock pattern, and damage potential.

Masonry structures are widely used structures and are highly susceptible to earthquake damage. A coordinated research project is underway to provide the research necessary to develop a rational limit state design methodology for reinforced masonry construction. This is a part of the U.S.-Japan coordinated program for masonry building research. Information obtained from the Mexico earthquake will prove invaluable in calibrating methodologies developed under this program.

A major U.S.-Japan cooperative research program of large-scale experimental research on reinforced concrete buildings is nearing completion. The ultimate objective of this program is to improve design practice through joint research. Significant impact to the professional practice in seismic design is expected and results have begun to appear in conference proceedings and special reports. The Mexican earthquake could provide a missing link toward understanding of full-scale concrete building behavior under actual intense earthquake conditions.

A research project has been undertaken related to steel structures in another U.S.-Japan cooperation effort. This is a large scale experimental effort with the ultimate goal of improving the professional practice in earthquake engineering and the design of steel structures. The Mexican earthquake will make it possible to calibrate our analytical and experimental techniques.

Dissemination of research results to improve the knowledge of engineers, architects, building officials, government officials and researchers is an important part of a successful Earthquake Hazard Mitigation Program. The Natural Hazards Information Center at the University of Colorado and the National Information Service for Earthquake Engineering with components at the University of California and the California Institute of Technology are two examples of NSF's dissemination program. The Mexican earthquake could provide an excellent opportunity to learn whether dissemination methods were an important factor in the failure of modern buildings in Mexico City.

The EHM program is providing significant resources for the upgrading of earthquake engineering research laboratories through research equipment grants such as at the University of California-San Diego and the University of California-Berkeley.

One of the programs we are considering for 1986 is support for an Earthquake Engineering Research Center. Such a research center would allow indepth, coordinated, focused, and systems research on earthquake engineering to be conducted. Some of the significant features of this proposed research center would be the dissemination of research results to users, more focused research and problem solving, and the involvement of industry leading to improvement and upgrading of the professional practice and increased U.S. competitiveness in the international arena.

A research project aimed at increasing the seismic resistance of existing unreinforced masonry buildings has been completed. The significant and well received research results have been used as the basis for strengthening several existing buildings in the Los Angeles area and for building code decisions. At this time the results are also being used for proposing building code modifications in Charleston, South Carolina. Vital information on the behavior of existing masonry buildings may be available by studying the Mexican earthquake.

Failures during earthquakes are often attributed to loss of the ability of subsurface foundation materials to support a foundation by a process called liquefaction.

Through NSF grants to the Earthquake Engineering Research Committee of the National Research Council and the Massachusetts Institute of Technology, knowledge on liquefaction has been assessed and placed in a useful framework through a workshop that was conducted during September, 1985. Two more of these national meetings are planned.

An important part of the NSF earthquake engineering research program is the support of lifeline systems research. Ths includes such systems as water distribution systems, communications systems, transportation systems, and power distribution systems. The appropriate functioning of these lifeline systems is necessary in order to respond to the effects of earthquakes. The Mexican earthquake could provide valuable information vital to calibrating analysis and design methods for such systems.

Although we have only received preliminary reports, I would like to describe briefly some aspects of the Mexico earthquake of September 19, 1985 of which we are aware.

The epicenter of the earthquake was approximately 230 miles from Mexico City and was located along the tectonic plate boundaries extending along the west cost of Mexico. This places the epicenter approximately 650 miles south of the U.S.-Mexico border. As is well known, similar conditions are present along portions of the U.S. West Coast and thus the environment exists for similar major earthquakes in the U.S.

The earthquake was along a type of plate boundary known as a subduction zone, that is, a type of interaction whereby one giant lithospheric plate thrusts beneath another. A tectonic environment with some important similarities with western Mexico, i.e., a subduction zone, is found near the northwest coast of the continental United States along the coasts of Washington and Oregon. By contrast the plate interaction along the San Andreas system in California is of a different type known as a transform or strike-slip boundary whereby one lithospheric plate moves sideways past another. Another major subduction zone is found along southern Alaska and extending westward into the Aleutians. In some of these areas the known earthquake potential is very high and confirmed by the existing seismic record. Along other areas particularly northwestern United States, the earthquake potential requires careful investigation.

Initial reports of the Richter magnitude of the earthquake were magnitude 7.8 but this was subsequently upgraded to magnitude 8.1. This underestimate of the size of the event (and consequently of the potential damage and the likely size of larger aftershocks) resulted from the limited amount of data quickly available from the present worldwide seismic network. Data from many of the stations are still not available and it will be some time before detailed studies of the earthquake source mechanism and of the pattern of aftershocks can be completed. When the Global Digital Seismic network is fully deployed, complete and accurate information on earthquakes anywhere in the world will be available almost immediately.

The magnitude of an earthquake indicates the total amount of energy released by the earthquake but this only provides a rough indication of how the ground may actually move at a specific point on the surface. The surface motion is of vital concern to engineers who must design facilities to resist such motions but is of less interest to seismologists and geophysicists. There are vast differences in scales of concern to the two groups—scientists tend to work in scales related to crustal dimensions or to geologic formations while engineers must be concerned with dimension of hundreds of feet related to the scale of constructed facilities. Because of these differences of interest and of scale, different types of measurements are needed by the two groups.

In order to capture information on the actual level of ground motions and the engineers characteristics of such motions, special strong-motion instruments have been developed. Two significant sparse networks of such instruments were in place in Mexico at the time of the earthquake. One was a joint U.S.-Mexico effort which placed instruments along the Mexicon west coast. The U.S. investigator for this project is Prof. James Brune of the University of California, San Diego. It appears that several of the instruments may have bracketed the earthquake epicenter and may produce the most significant near fault strong-motion records ever obtained from an earthquake. Because of the remote location of the instruments and the desire to capture aftershock information, I cannot yet show you these records. We have obtained, however, some preliminary data recorded in Mexico City itself and I would like to show you some of these records.

Shown first is a recording obtained on firm ground at the Institute of Engineering at the University of Mexico. Peak accelerations in this record are about 4 percent of the acceleration due to gravity. Next a recording from the site of the Communications and Transportation Building located on the old lake bed is shown. On these

records the peak accelerations are about 18 percent G which is about 4 to 5 times the maximum peaks of the previous record on firm ground. This does not come as a surprise as it has been known for a long time that significant ground motion amplification can occur on soft soils during earthquakes. For example a 1964 paper by Dr. Leonardo Zeevaert in the Bulletin of the Seismological Society of America provided an analysis of Strong Ground Motions Recorded During Earthquakes of May the 11th and 19th, 1962 in Mexico City. The general conclusions of this paper were that site amplification effects of 300 to 400 percent are possible at low levels of damping at the natural frequency of the site.

An indication of the effect of such site amplification and filtering effects of the propagating earthquake waves can be seen by examining a graph showing the behavior of a simple structure, which would look something like a heavy golf ball sitting on top of a thin flexible supporting tee. By using a large digital computer it is possible to examine the behavior of this simple system when the ground supporting it undergoes the motions actually recorded by engineering instruments during the earthquake. The characteristics of this simple structure can be preset for the computation so that the natural vibrational frequencies or time period required to complete a cycle of motion is known. The maximum response of a set of such structures can be examined for an actual recorded ground motion and different natural frequencies for each simple structure. When the maximum calculated values of response for each of the simple structures is plotted against the natural period for each of the simple structures, a picture of how the earthquake might affect elementary structures is obtained. When this is done for ground motions recorded on the soft soil layers in Mexico City, it is found that a very sharp peak in the curve appears at a period of oscillation of about 2 seconds. Another definite peak occurs at about a 2.4 second period. In this case the peaks are indications of the resonances in the soft soil generated by the distant earthquake.

The most serious damage was to reinforced concrete buildings in the range of 8 to 14 stories in height. This is in part due to the fact that with design practices used in Mexico such buildings would have a first natural period of vibration on the order of 2 seconds which would generate strong coupling action with a natural period of vibration of ground motion. Any building or structures having vibrational characteristics involving a 2 second time period are likely to react most strongly to this earthquake. Such a typical situation is generally considered in the design of structures. Due to slightly different design practices, similar buildings in the U.S. would probably have slightly lower periods on the order of 1 to 1.5 seconds but this fact in itself is not an overly significant factor in the behavior of the structures.

In addition to damage to concrete structures there was damage to some steel structures and to lifeline systems. For example one of the main aqueducts bringing water to Mexico City failed which has caused a serious water supply problem. On the other hand the subway system in Mexico City evidently suffered little damage. This is as we would have predicted because the subway tunnels are small compared to the characteristic dimensions of the earthquake waves propagating through the soil.

Other serious problems arose in connection with fires which complicated removing trapped victims from collapsed structures and in the overall organization of relief efforts. The reports of our reconnaissance teams collecting perishable information will no doubt highlight many other problems.

Disturbing questions arise concerning the knowledge-base available for earthquake resistant design of structures and whether there is a problem in the level of training available to building design teams. Many Mexican engineers and architects were trained in U.S. institutions, are recognized for their research contributions around the world, and are either in practice in Mexico or are on the faculties of Mexican academic institutions. Our cooperative U.S-Mexico earthquake engineering research programs reflect this situation. From this it might be concluded that modern building designs in Mexico City probably represented current state-of-the-art practice as would also be applied in the U.S. However, many of the designs appeared to be inadequate. Initial reports indicate that a major problem was that the high intensities of ground motion and the unusually long duration of shaking could not have been predicted using our current state of knowledge.

The critical question is why such poor performance occurred to so many structures in a known earthquake zone. Part of the answer may be due to older existing buildings which were constructed without benefit of current knowledge and practices. This would not explain, though, the behavior of newer structures constructed under the current code. We must look then to the earthquake itself. Several features of this earthquake were quite different and were vitally important in comparing the actual building performance to what had previously been predicted. First

the absolute intensity of motions developed on the old lake bed were much greater than had been predicted. Second the duration of strong shaking was much longer than is normally the case for strong earthquakes resulting in structures which had coupled responses driving them through more cycles of damaging deformation than might have been expected. This results in the structural capability degrading with each cycle.

Many lessons can be learned from the Mexico earthquake which would be of benefit to providing greater earthquake safety in the U.S.

The accuracy of predicting the actual intensities of ground motion to which structures may be subjected during an earthquake is still an open area of research. Such accurate information is vital because without it engineers and architects are faced with a dilemma regarding what loading conditions they should design for. Too conservative a loading requirement will result in buildings which are more expensive than need be. Too liberal a loading requirement may result in structures which could collapse or sustain unacceptable levels of damage.

The instrument data from the Mexico earthquake provides an opportunity to improve our methods for predicting actual intensities of ground motion and structural response taking into account local ground conditions, nature of propagation path, duration of shaking, distance of propagation and other factors which may affect the coherence of the surface ground motion. In order to capitalize on those opportunities additional research should be focused on: Subsurface drilling and sampling, subsurface insitu testing cross-hole seismic surveys, seismic reflection surveys, seismic refraction surveys, Ambient measurements on unfailed structures, forced vibration tests on unfailed structures, computer processing and analysis of strong motion data recordings, Micro seismic surveys, and computer modeling of existing unfailed structures.

The availability of new supercomputers will make it possible to evaluate these data in a way which would not have been previously possible.

An evaluation of structures which did not fail may be as important as studying structures which did fail. It may well be that "simplified" methods of analyses of dynamic behavior of complex buildings and structural systems are not adequate. The consequence of such a conclusion would be a need for more rational analysis techniques, better computer methods and software, better information on material behavior under severe loads and better methods of analysis in engineering practice.

The drama of collapsed structures has been highlighted in early reports. However, much information is probably available on the performance of architectural and mechanical systems. Such structures may still be standing but their functions are impaired by the loss of architectural and mechanical systems. Included in this category are lifeline systems such as water supply, sewage disposal, electricity, transportation and communications.

The chain of events resulting in many collapsed structures with trapped persons has shown there is a need for an improved knowledge base for locations and rescuing such people. This area of research has not received high priority in the past in comparison with other needs.

Some of the problems experienced in the Mexico earthquake are ones that have been under study in our NSF/EHM research program. This disaster presents us with a major opportunity to greatly increase our knowledge about earthquakes and their effects and possibly to prevent a similar disaster from happening in the U.S. We will do what we can to obtain the data and information to maximize our understanding from this most unfortunate laboratory experiment that nature has given us.

Senator GORTON. Thank you, Dr. Suh.

Your written statement will be included in the record.

Dr. Lyons.

Dr. LYONS. Thank you, Mr. Chairman.

Good morning, and thank you for the opportunity to appear at this hearing. With me are Dr. Richard Wright to my far left and Dr. Edgar Leyendecker immediately adjacent. Dr. Wright, a structural engineer, director of the NBS Center for Building Technology, is in charge of NBS's role day by day in the National Earthquake Hazard Reduction Program.

Dr. Leyendecker, also a structural engineer, is just back from Mexico City, where he led the NBS/USGS team. These gentlemen are the experts. You will be particularly interested, I think, in Dr.

Leyendecker's summary report, which will consist of a videotape. So I will try to be very brief.

First, let me say that the Bureau's role under the National Earthquake Hazard Reduction Program is to facilitate the improvement of the building regulations in the United States with regard to seismic resistance.

We do this in a number of ways. Dr. Wright, for example, chairs the Interagency Committee on Seismic Safety and Construction. We work with the Building Seismic Safety Council to move along improvements in practices as they are learned. We are conducting the design concept study for a national earthquake engineering experimental facility on behalf of our colleagues in the other agencies.

We cochair the United States-Japan Panel on Earthquake and Wind Effects, and to support all of these activities we conduct a program of research in the structural aspects of the problem at the Bureau of Standards.

The NBS/USGS team spent the time from September 24 to September 29 in Mexico City. They provided technical assistance to the U.S. Embassy. They reviewed the situation with regard to structures in the city to the best of their ability.

They advised U.S. rescue workers and Mexican Government officials on some of the technical aspects of the rescue efforts, and as I indicated, Dr. Leyendecker will show you some of the things that they encountered.

Furthermore, we have summarized some of that information in a preliminary way in the written statement.

Let me make a few comments about the status of the U.S. building regulations. We begin in this system with the three model building codes.

The uniform building code in the Western United States is designed to provide enough structural stability for escape of people even in the strongest earthquakes. In the strongest earthquakes we would be willing to accept considerable structural damage, but we are not willing if we can help it to accept loss of life.

Not all communities adopt the model codes. Some write their own. Some do not have any. Not all communities that adopt a code adopt the seismic provisions. The provisions that are now in the code would protect most buildings in a severe earthquake.

I cannot say all buildings, because we do not know everything, and the gentlemen on the panel have already indicated some of the surprises we have encountered in this latest tragedy.

Furthermore, the current thinking on seismic resistance is not entirely yet in the model codes, but is in the process of being introduced. The process of making changes in model codes which have been adopted by communities and eventually become local ordinances is a deliberate and careful, but time-consuming, process. It often takes several years to make significant changes in these codes.

A parallel effort in building regulation now is underway for Federal buildings and for those buildings that receive some kind of Federal support. That effort is being managed via the interagency committee that I mentioned, and if you have questions about the status of that, Dr. Wright can provide some detail.

Now I would like to introduce Dr. Leyendecker, who will summarize on videotape what the group found.

[The statement follows:]

STATEMENT OF DR. JOHN W. LYONS, DIRECTOR, NATIONAL ENGINEERING LABORATORY, NATIONAL BUREAU OF STANDARDS

Mr. Chairman, thank you for the opportunity to testify on behalf of the National Bureau of Standards (NBS) on what might be learned from the tragic Mexican earthquake of September 19, 1985, and the consequent possibilities for improvement of seismic design and construction practices. I am accompanied by Dr. Richard N. Wright, Director of the Center for Building Technology, and Dr. Edgar V. Leyendecker who led the NBS/U.S. Geological Survey (USGS) team investigating the damages in Mexico City.

In the National Earthquake Hazards Reduction Program (NEHRP) NBS provides technical support to the development of seismic design and construction practices for use in the building codes of State and local governments and in the building programs of Federal agencies, and conducts requisite research. With your permission, I offer for the record [1] the description of NBS activities prepared for the Fiscal 1985 report of the NEHRP. In summary:

The Interagency Committee on Seismic Safety in Construction (ICSSC) assists Federal departments and agencies involved in construction to develop and incorporate earthquake hazards reduction measures in their programs. With financial support from the Federal Emergency Management Agency (FEMA) NBS provides the Secretariat for the ICSSC, Dr. Wright chairs the ICSSC and Dr. Leyendecker chairs its subcommittee on Standards for Buildings, and NBS co-chairs its subcommittee on Post Earthquake Response Activities.

The Building Seismic Safety Council (BSSC) is an independent, voluntary body, established under the auspices of the National Institute of Building Sciences, to enhance the public safety by providing a national forum to foster improved seismic safety provisions for voluntary adoption by the building community in planning, designing, regulating and using buildings. With financial support from FEMA, NBS since BSSC's inception has provided technical support for the BSSC and technical secretariat for the Overview Committee of BSSC. BSSC's Recommended Provisions for the Development of Seismic Regulations for Buildings are now undergoing ballot by BSSC members which will be completed in November, and BSSC is developing an implementation plan for encouraging widespread application of the provisions throughout the U.S.

NBS research has produced new data and improved test methods for predicting the susceptibility of soils to liquefy when subjected to strong earthquake shaking, and data and techniques for predicting the earthquake resistance of masonry walls. A large scale seismic facility has been developed for testing resistance of structures to seismic loading and is being used to study the resistance of full scale bridge piers with financial support from the National Science Foundation (NSF), the Federal Highway Administration, and the California Department of Transportation.

At the request of the President's Office of Science and Technology Policy, with financial support from FEMA and the NSF, NBS is doing the design study for a National Earthquake Engineering Experimental Facility. The goal of the facility would be to provide the data, at approximately full scale, and understanding necessary for rapid improvements in the design and construction of earthquake resistant structures.

The U.S.-Japan Panel on Earthquake and Wind Effects brings together 15 U.S. agencies and their Japanese counterparts for cooperation in research and development of earthquake hazards reduction practices. NBS provides the U.S. Chairman and secretariat for the Panel. Current cooperative work includes large-scale structural testing, post-earthquake investigations, strong motion instrumentation and data, and evaluation and repair of existing structures.

Under the auspices of the Agency for International Development's Office of Foreign Disaster Assistance, NBS and the USGS (USGS) dispatched a team of investigators to Mexico City from September 24 to 29, 1985. The team provided technical assistance to the staff of the U.S. Embassy and identified possibilities to learn lessons from successful and unsuccessful structural performance that can assist in the improvement of U.S. seismic design and construction practices. Team members are: Dr. Edgar V. Leyendecker, Structural Engineer, NBS, Leader; Dr. William Stone,

[1] The material referred to has been retained in the committee files.

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Structural Engineer, NBS; Dr. Felix Yokel, Geotechnical Engineer, NBS; Dr. Thomas Hanks, Seismologist, USGS; Dr. Mehmet Celebi, Engineer, USGS.

The Team advised U.S. rescue workers and Mexican officials on means to more rapidly remove debris from collapsed buildings to speed the search for survivors, and worked with Mexican experts to identify fruitful opportunities for indepth studies of structural performance.

Team representatives also briefed the U.S. Ambassador to Mexico and his staff on the earthquake. This included cause of the earthquake, possible reasons for such large ground motions, and possible reasons for the observed structural failures.

The Mexican earthquake is more than an example of the many injuries, and losses of lives, property, economic activity, and national security caused by earthquakes. Out of the tragedy also comes valuable data on full-scale structural performance to better understand earthquake mechanisms and effects in order to reduce future losses. Although it is too early to reach conclusions on details, we can say the following:

For this large, distant earthquake, damages were especially severe for taller buildings on soft soil deposits. Examples of successful performance as well as severe damage are available. Indeed, most buildings performed well.

Earthquake intensity apparently varied markedly over relatively short distances due either to changes in soil deposits or to systematic or random variations in dynamic motions. We hope to gain important knowledge on the local variations of earthquake intensity.

A large variety of buildings were exposed to the earthquake. Performance information is available on both conventional and innovative systems of interest for U.S. practice. Engineers will be able to assess the effects of successive improvements made in the seismic code for Mexico City in 1942, 1957, 1966 and 1976. The efficacy of repair techniques can also be ascertained from the performance of buildings repaired after being damaged in 1957, 1968 or 1979 earthquakes.

Particular emphasis should be given to recovery and dissemination of strong motion records relevant to areas of significant structural performance; effective research requires knowledge of ground motions.

Mexican engineers and seismologists are recognized around the world for their expertise. Since our countries are good neighbors and professional relationships are excellent, collaborations on investigations are feasible and cost-effective. Since Mexico has financial difficulties exacerbated by earthquake losses, U.S. support for participation of Mexican investigators may be needed to take full advantage of the many opportunities to gain new knowledge.

NBS technical support for the private sector Building Seismic Safety Council (BSSC) and the Interagency Committee on Seismic Safety in Construction (ICSSC) provides good background in the status of seismic design and construction practices in the U.S. I offer for the record the report of the Workshop on Implementation of Federal Seismic Provisions in the Building Programs of Federal Agencies—March 19, 1984, of the ICSSC which describes U.S. seismic design and construction practices. In summary:

Building codes of State and local governments are based largely on one of the three model building codes and/or national standards. However, many building codes in areas of substantial seismic risk do not adopt seismic design and construction provisions of a model building code or the national standards. None of the model codes completely references the latest national standards for seismic loads and resistance.

The majority of Federal agencies that design and occupy buildings use criteria similar to those of the Uniform Building Code (the model code with the most rigorous seismic design and construction provisions for normal buildings). Such buildings are intended to: (1) Resist minor earthquakes without damage. (2) Resist moderate earthquakes without structural damage, but with some nonstructural damage. (3) Resist major earthquakes, of the intensity of severity of the strongest experienced in California, without collapse, but with some structural as well as nonstructual damage.

Critical buildings, such as hospitals, are designed to a greater level of safety.

Ongoing research seeks knowledge to accomplish and strengthen these objectives. The Mexican earthquake experiences will test current U.S. design and construction practices in situations where Mexican design and construction is similar to that which would be called for by the Uniform Building Code or other U.S. seismic design and construction provisions.

Agencies which lease buildings or support their construction under grant programs tend to use local building codes. Such buildings would be expected to perform

as well (or poorly) as their private sector counterparts in a locality struck by an earthquake.

ICSSC has drafted a seismic standard for Federal buildings based substantially on the Uniform Building Code provisions for seismic resistance but incorporating more recent national standards for seismic loadings and recommendations under consideration by the BSSC.

The Workshop on Implementation of Federal Seismic Provisions recommended:

1. The Federal Emergency Management Agency should draft an executive order requiring Federal agencies to adopt common seismic provisions for new buildings.
2. The order should be flexible to allow for the inclusion of the special requirements of the various agencies.
3. The order should reference the draft seismic standard of the ICSSC as the common seismic provision.

The ICSSC is working to effect these recommendations. The ICSSC has drafted and is balloting a proposed seismic standard for new Federal buildings and a proposed executive order for use of seismic design and construction provisions in Federal and Federally assisted construction.

Dr. LEYENDECKER. The dates of our visit to Mexico City have already been mentioned. I would like to reemphasize some of the points that have already been made, and these will come up rather naturally during the course of the discussion.

First of all, Mexico City was not a city in shambles after the earthquake. Many, many buildings performed well, in fact came through quite nicely, but there are some areas of the city that were very hard hit, and I will show you some examples, and only examples of these particular areas. As we go through the videotape, I think the overflight will give you an idea in general how the entire city came through the earthquake, both low-rise structures and high-rise structures. Many performed quite nicely.

We have already mentioned the problems of resonance in buildings 5 to 15 stories tall, and that certainly accounts for some of the problems that occurred in the buildings, but most likely not all of the problems that were encountered.

[Videotape shown.]

This is a view of the Continental Hotel, which was on the Avenue Reforma. It indicates some of the damages that occurred to that structure in the upper stories.

This is a series of Juarez apartment buildings. This brings up an example of a question that was raised earlier. Why was this building badly damaged when surrounding possibly identical but I am sure rather different in some construction details, why did they not collapse? That question comes up over and over again.

This is the Mexico General Hospital. The first building was six stories in height, and it completely collapsed. This was reinforced concrete. The second building was some eight stories in height. Once again, it completely collapsed. Reinforced concrete comes up over and over again as being a structure type that collapsed, but it is also necessary to point out that much of the construction in Mexico City was reinforced concrete.

This is the reason it was so difficult to get communications out of Mexico City immediately after the earthquake. This is the communications building, and as you can see, it underwent rather severe damage. From the ground you can get a little better idea of the damages to that structure. We saw upper stories collapsed, and sometimes intermediate stories collapsed.

If you look in the yellow boxed in area on the screen, what appears to be one story is actually two stories, but one of the stories

has had all of the columns severed so that the upper several stories have actually impacted down upon the building. It raises questions of why all of the columns in that particular level collapsed—was it quality of construction or dynamic response of the structure, for example?

We will be moving in just a moment to the opposite side of that building to give you once again a feeling of the difficulties for this structure, which really should be considered an essential kind of facility as far as communication goes with the outside world. Note that this structure was undergoing some demolition, removal of documents, removal of computer equipment, and so forth.

We have seen this picture somewhat earlier, if you recall, the steel building on the ground in the foreground and the two structures in the background that are still standing. They are not in quite as good a shape as they might have appeared at first glance, and I will show you that in just a second. We are always interested in steel structures, because their performance in earthquakes is generally quite good, when they fail we need to learn why.

I call your attention now to the circled building that was immediately behind the one in the foreground that collapsed. If you look at it, you can see it has got a definite tilt and twist to it. It is actually in quite severe condition, even though it may have looked otherwise in earlier views.

This is Juarez Hospital, a 12-story reinforced concrete building. This was in the week after the earthquake. We still have 12 stories of slabs on the ground. There were reported to be somewhere between 800 and 1,000 people in this structure. Something like 50 or 60 survivors have been recovered.

Rescue techniques here were primarily tunneling into the debris, in between floor slabs, a very slow process.

This illustrates another possible reason for some of the severe damages within the city. Frequently there were adjacent buildings, one perhaps eight, nine stories tall, adjacent to a four-story building, where the taller building would be collapsed down to the level of the shorter one.

If you look closely at the structure, which was adjacent to the one that collapsed, look in the upper three stories. You will observe the column bases. They are kicked way in. These two structures were undergoing what we would term pounding or hammering.

They were literally beating each other to death. The one on the right won, and it met the design criteria of not collapsing, but the one on the left certainly did not. In this case additional building separation would certainly have enhanced the performance of that particular structure.

We observed many columns sticking straight up, almost like a forest of trees. This particular slab construction failed many times by this punch-through kind of failure, and I think there are some reasons for observing this kind of construction and studying it, because it is widely used in Mexico City.

There are a lot of lessons that can be learned here, I believe. Some of them have already been mentioned, and if our Mexican colleagues and research workers there are as cooperative after the earthquake, which I am sure they will be, as they were in the first few days following the earthquake in terms of sharing data on ac-

celerations, building damages, and so on, I think there is a wealth of data that we can learn from, in spite of the tragedy and human loss of life and injury to property.

Thank you.

Senator GORTON. Does that complete your testimony?

Dr. LYONS. That completes our testimony.

Senator GORTON. Dr. Peck, let us now consider the various kinds of tectonic settings in the United States, those which are similar to Mexico and those which are dissimilar to what we saw in Mexico City. Would you explain these different tectonic settings, including that in southern California, the Puget Sound, the Midwest, and other areas? Then would you answer the question, does it make any difference once an earthquake comes whether or not these faults were dissimilar from one another?

Dr. PECK. I will tackle the first one. I think I am going to draw on Dr. Filson to help me on the second one.

As I explained, the situation in Mexico is an underthrusting of the Cocos plate under the North American plate. The situation is different in California, because what we have there instead of that underthrusting a lateral slip along the San Andreas and related faults. When we get to Oregon State and Washington State and Alaska, we have an analogous situation, and that is, the Juan de Fuca plate is underthrusting the North American plate along the coast of Oregon and Washington. As a result, there are active volcanoes along the Cascades. That is a typical situation.

The rate of convergence of the two plates is about half what it is in Mexico, and there has been a fair bit of discussion about whether that movement is taken up aseismically just by the two plates moving across each other without earthquakes or whether it is building up toward a major earthquake. That is still a matter of debate.

Now, the situation in Alaska and the Aleutians is again very similar to Mexico, and the earthquake that occurred on Good Friday in Alaska in 1964 was a similar earthquake.

Senator GORTON. To that of Mexico City?

Dr. PECK. Yes, with underthrusting of the Pacific plate under the American plate in Alaska. My understanding of the situation in the midcontinent in Missouri and western Tennessee is that it is a third, different situation. That is an ancient rift zone geologically.

The area is similar to Mexico City in that there are water-saturated sediments deposited by the Mississippi River, particularly the flood plain of the Mississippi River; but the tectonic situation is different.

At that stage I think I have reached the limit of my understanding, and let us let Dr. Filson——

Senator GORTON. Before we go to him, have we now exhausted both the locations and the types of tectonic situations in the United States?

Dr. PECK. No, indeed. There are, of course, many earthquakes in the Great Basin. Those are due to steep faults and the mountains getting higher and valleys getting lower. That is another kind of earthquake. There are historic earthquakes in Charleston and elsewhere along the eastern seaboard.

I am not sure we know exactly what the tectonic setting is, but it is certainly different than that in Mexico or along the San Andreas fault in California. So there are a number of different tectonics.

Dr. FILSON. My name is John Filson, from the Geological Survey. The plate geometry can make a difference in the types of acceleration and ground motion that are experienced in an earthquake. The propagation of the earthquake rupture can tend to focus energy—cause large displacements along the direction of propagation.

If a plate is underthrusting a continental margin, the whole rupture surface can radiate energy to sites in the continental block. These effects can be, in my opinion, as large as the local site effect, but in general I would imagine that the local site effects would be greater than the effects due to plate geometries and rupture propagation.

Senator GORTON. Now, I am not sure. It may be USGS to which this question should be directed, but if other witnesses wish to answer it, I would be happy to have them answer it as well.

Where are we today with respect to our ability to predict earthquakes within a timeframe that will allow us to do something about it? Is this impacted by the type of tectonic situation with which we are dealing? Is it easier in one place than another?

Dr. PECK. Let me take a crack at that and perhaps then turn to Dr. Filson to amplify.

At this stage we, and by we I mean the whole world earthquake community, have very limited ability to predict the time, place, and magnitude of earthquakes. We have made a lot of progress on predicting the recurrence interval of earthquakes and hence the recurrence in a broad time sense of an earthquake and the earthquake magnitude and place.

So, for example, this earthquake was anticipated in a general way because there was a seismic gap. One can calculate the plate movements that have occurred since the last earthquake, and hence the buildup of strain. So in a general way we can predict, but as far as predicting the exact time, we do not have that ability now. We are still determining whether indeed it is feasible to do that.

Now, some earthquakes have been predicted in the past, and predicted accurately. The Chinese predicted the occurrence of a major earthquake a few years ago and evacuated the city. The earthquake occurred. The city fell down—and the people were not hurt.

So, it can be done. A lot depends on the nature of the tectonic setting and the fault and our knowledge of the historic occurrence of earthquakes and the occurrence of premonitory phenomenon before that.

We have an intensive study going on at Parkfield, CA, where there have been recurring earthquakes of a magnitude about 6 every 22 years for the last 100 years. It comes up again in 1987 or 1988, and we are doing intensive study with our colleagues at the universities trying to see whether we can see premonitory phenomenon.

Senator GORTON. Senator Gore.

Senator GORE. Thank you very much, Mr. Chairman.

Dr. Peck, can you rule out further aftershocks for Mexico City?

Dr. PECK. I think there is a general tailing off of aftershocks. It goes on for some time. We have been surprised at how few large magnitude aftershocks there have been. But again, Dr. Filson will be more knowledgeable.

Dr. FILSON. No, sir, we cannot rule out further aftershocks in the sequence that might affect Mexico City.

Senator GORE. Has the probability of further aftershocks declined with the number of days passing since the initial event?

Dr. FILSON. Yes, sir. That is a general trend. The farther in time you get away from the main shock, the less probable are large events.

Senator GORE. Are they still in a dangerous period?

Dr. FILSON. I would say that aftershocks from the sequence will be detected over a period of months perhaps a year.

Senator GORE. Now, you talk about particular seismic zones as being overdue for an earthquake because of the past historical record and the building up of stresses and so forth. What areas in the United States are overdue for an earthquake?

Dr. PECK. I mentioned Parkfield, where it is going to be due in the next very few years. We have determined that the recurrence interval in southern California, for example, is about 150 years. It has been 130 years since the last earthquake.

In the southern California region, the last earthquake was in 1857. It is one of those seismic gaps. There are several areas in Alaska. There is one, if you will pardon the expression, in the armpit of Alaska, the Yagataga Gap in southern, eastern Alaska, where seismologists have——

Senator GORE. You are lucky Senator Stevens is not here.

Dr. PECK. It is also a seismic gap there, too. Those are two that come to mind.

Senator GORE. And the others? What about in the eastern United States?

Dr. FILSON. There are regions in the eastern United States that have experienced earthquakes in the past, such as Charleston, SC, and others, but we do not have enough evidence. We do not have a long enough historic record of the seismic history in these regions to establish reliably recurrence rates.

Senator GORE. Now, it is true, is it not, that the largest earthquake ever to take place in the continental United States was the New Madrid, and if you take those three quakes from December of 1811, through February of 1812, those three quakes together produced more or released more earthquake energy than all of the other quakes in known history in the continental United States combined?

Dr. FILSON. Yes. It is probably the most energetic region over historical time.

Senator GORE. Now, you talked about the soil conditions in Mexico City, and you drew a comparison between the soil there and the soil lying underneath the area around New Madrid. What are the similarities? Is that just the siltation from the old flood plain?

Dr. PECK. It is saturated fine grade sediments.

Senator GORE. Because of those soil conditions underneath Mexico City, we saw the propagation of damage far distant from

the epicenter of the quake. Is it not true that generally speaking earthquakes in the western United States are unlikely to propagate over such distances because of the geology in the West?

Dr. PECK. That is right. The seismic energy does not propagate as far in the West as it does in the East.

Senator GORE. But in the eastern United States generally speaking a large quake is likely to cause damage over a much larger area. Is that correct?

Dr. PECK. That is true.

Senator GORE. All right.

Now, Dr. Speck, you recently completed a study of the potential effects of major earthquakes on six cities in the United States. I am particularly interested in the results in one of those cities. Could you briefly summarize the conclusions that FEMA reached about Memphis?

Dr. SPECK. I am going to ask Gary Johnson, who is Acting Director of our Division of Earthquakes and Other Natural Hazards to respond to that.

Briefly, Senator, that report is in printing, and does focus specifically on the damages in different areas of those cities.

Senator GORTON. What are the other five cities?

Mr. JOHNSON. Senator, the other five cities are Paducah, KY; Little Rock, AR; Evansville, IN; Carbondale, IL, and I am missing one in my mind right now.

Senator GORTON. Go ahead.

Mr. JOHNSON. Our basic——

Senator GORE. What was the fifth one?

Mr. JOHNSON. Poplar Bluff. An additional study right now is being done in St. Louis, and we have also received a draft report looking into the effects of the earthquake on tall buildings in the distant cities of Chicago, Kansas City, Dallas, and Atlanta. We are currently evaluating that.

Senator GORE. Tell us what your findings were with respect to Memphis. Give us a preview of this report that is at the printers.

Mr. JOHNSON. What we found in Memphis is a very astronomical dollar loss in terms of money. That is primarily related to the unreinforced masonry construction in the city of Memphis. I think we are talking in the neighborhood, Senator, of about $33 billion worth of loss in that particular area.

Senator GORE. $33 million?

Mr. JOHNSON. $33 billion.

Senator GORE. $33 billion with a "b?"

Mr. JOHNSON. That is correct: From a recurrence of the 8.6 earthquake that occurred back in 1811. The amount of loss of life in the area escapes me at this point. It is significant. It is clearly the greater than in the other five cities.

Senator GORE. I believe it was in the area of 5,000 to 6,000.

Mr. JOHNSON. Yes, that is the correct parameter, certainly, and the major problem in that area, particularly during the day, is with the unreinforced construction of school buildings and children in the schools at the time.

This is certainly something that we need to address in the area, and it brings up a point not only unique to Memphis but everywhere else: The problem that existing hazardous construction poses

to us, not only in Memphis, but throughout the country, and the need to develop processes, code provisions, and so forth to be able to abate the existing hazardous buildings, particularly schools and other critical facilities.

Senator GORE. Well, the lesson we ought to learn from these astounding figures is not that we should be frightened of the fact that an earthquake is probably inevitable at some point in the future. The lesson we should learn is to begin making preparations now to strengthen these buildings, to have codes that require future construction to take place in a safe manner. We also need public education. Indeed, many of these efforts have now begun in Memphis. But if I understand the testimony of this expert panel, the evidence that you have compiled is very troubling, because the damage would be tremendous, and we must step up our efforts to prepare against the eventuality of an earthquake in the New Madrid area.

Mr. Chairman, my time is expired, I know.

Senator GORE. Senator Ford.

Senator FORD. Thank you, Mr. Chairman.

This is not one of my subcommittees, but it gets awfully close to home.

Senator GORTON. Paducah was one of them.

Senator FORD. Well, Evansville, IN, is 29 miles from my home town.

Dr. Peck, we talk about the New Madrid and you indicate that it would be much worse than other areas, and has been. Something that occurred on the Mississippi River and rang church bells in Boston was a pretty good tremor. We have some estimates that rank the probability of a new quake from 40 to 60 percent in a few years, and 85 to 95 percent a little bit further.

How close, with certainty in your own mind, could you say that there would be another quake in the New Madrid fault?

Dr. PECK. Well, for that I will turn to Dr. Filson.

Dr. FILSON. It is very difficult, Senator, to estimate an exact time. I think we would have to stick with the probability statements that have been repeated or that have been expressed here earlier, that a magnitude 6 event has a probability on the order of 40 or 60 percent in the next 15 years.

Senator FORD. Now, when we talk about New Madrid then and we talk about Evansville, IN, as the crow flies a distance of maybe 100 miles, would the effect at 6 be felt in the general area around Evansville?

Dr. FILSON. The earthquake, in my opinion, would be felt in the area. I would also estimate that the damage would not be severe at Evansville from an earthquake in New Madrid at the magnitude 6 level. There may be some damage, though.

Senator FORD. What about 7.6 or 8?

Dr. FILSON. In that case, certainly there would be, I would estimate, severe damage in that area.

Senator FORD. Let me talk to Dr. Speck just a minute then. In making the study of these communities, what kind of emergency preparedness situation do you find in Evansville and Paducah and the smaller cities, small in comparison to Memphis? I would say Paducah is around 50,000, Evansville is somewhere around 100,000,

Henderson is right across the river. The last quake I think diverted the Ohio River and Evansville is Indiana instead of Kentucky, but they are just right there on top of each other.

Dr. SPECK. Senator, first of all under the integrated emergency management approach, all communities pretty much are working to develop the capability to do those kinds of basic functions you have to do in the face of any kind of disaster, being able to give direction, control, warning, being able to shelter people or being able to evacuate people, and medically care for people and the like, and that is where we are putting a good deal of our resources into developing that capability, and as part of that, what communities are doing, we started in 1984 and went to full field implementation throughout the country in fiscal year 1985 with the multiyear development program in which each community does their annual hazard analysis, vulnerability assessment, looks at the hazards in their particular area.

On the basis of that, then they look at what their current capability is, do their operations planning on that, and then look at the difference between that. the delta between that and where they need to go, and that goes into their plan and also is reflected in the State plan.

That is overall generic capability.

Now, you have to look at the specific earthquake hazard, which has certain kinds of things in terms of preparedness and mitigation that are unique, and what we have been doing is working with the communities that Senator Gore mentioned, the Central U.S. Earthquake Project States under the consortium of some seven States, to do a number of things. One that they are working on right now is public awareness, getting the public really keyed up in your area about the need for this kind of planning.

A second they are in the process of doing is doing an inventory of critical resources because they realize that Paducah is not probably going to be able to go it on its own. It is going to have to have help from other areas, and one of the things you know from the earlier New Madrid earthquake, and we know from that fault situation, is that it could be in different areas of the fault area, and the studies reflect that, so that they are looking at ways in which they can support each other through an inventory of critical resources, these kinds of things.

They are also looking at interstate mutual compacts that will allow the communities in one State to support the communities in another.

I could go on but boil it down to say that through the consortium, the States and the localities within those States are looking at the earthquake threat from a perspective of what they can do to help out each other. We are working with them through a variety of mechanisms such as the vulnerability studies in those six cities plus now St. Louis and the cities further away, to help them develop the data base.

Senator FORD. In Mexico, one of the biggest problems I found, and apparently it was said here that others felt the same way, was communications.

Is there any way that you are working on communications needs, as an integral part of the total program? The biggest thing we had going for us was ham operators out of this community to Mexico.

I know when I was Governor we had emergency preparedness plan, and that it was all worked out, and we had certain places to go and people who would do certain things. Even in flood, we would have them out on the riverbank to check it every so often to—tie a string around a bush, if nothing else, to see how fast the water was rising.

But the communications of that information, and the communications out of the damaged areas seems to be critical.

Now, are you looking into the communications arena as it relates to our ability—I am talking about Paducah, Evansville, Memphis, and other communities—to be able to respond to what we need? Are you looking at what the problems are so that we might be able to respond in this respect?

Dr. SPECK. First of all, that is being looked at under CUSEPP, and second, that is part of our overall emergency preparedness planning in every community and in each State.

Senator FORD. Did we learn something from the Mexico problem as it relates to communications?

Dr. SPECK. Pardon?

Senator FORD. Did we learn something from their communications problem?

Dr. SPECK. Yes, I am certain that we will be looking at that very carefully to see if assumptions as to what we anticipate would be available and what we anticipate would have to be augmented in our national response plan that we tested in California were realistic, or whether the Mexico experience tells us that in some ways it was not realistic.

Senator FORD. One quick question, Mr. Chairman, and then I will stop, and I do thank you.

Dr. Lyons, I understand from reading and studying about the Mexico City problem that those buildings on what we call "floating concrete" sustained the quake much better than others based on traditional foundations and the mud they were sitting on.

Is that true?

Dr. LYONS. Let me, if I may refer that to Dr. Wright, Senator.

Dr. WRIGHT. Our observations of the performance of the buildings in Mexico have not reached the point of being able to compare the effects of various foundation types, deep piles or mat foundations, one with the other.

Senator FORD. All right.

Dr. Speck, could I have a copy of your report as it relates to Paducah, KY, Evansville, and so forth?

Dr. SPECK. Yes, sir.

Senator FORD. And one other thing I would admonish you. About every 6 months you ought to try to scare people.

We had a lot of write-up about all this, and people are really moving, but it is gone now. Every once in a while you ought to have someone go down and shoot off a flare.

Dr. SPECK. Mr. Chairman and Senator, if I might briefly respond, one of the things that I think has been positive in the Central U.S. Earthquake Project is the increased degree of public awareness in

a relatively short period of time, and that is critical for getting the public to be willing to support public officials' allocation of resources to do these kinds of things. They have had some very good success in that regard.

Senator GORTON. We are going to have to go on to another panel soon, as fascinating as you have been. Dr. Speck, you have talked around this question in your answers to Senator Ford, but could you give us the present status of our National Catastrophic Earthquake Response Plan on the part of FEMA, and tell us the extent to which you think that what we are learning in Mexico City is going to require any changes in that plan.

Mr. SPECK. Mr. Chairman, I will be calling on Joe Winkle, our Assistant Associate Director for Disaster Preparedness to back me up on this. He was out and played a major role, in fact, the major role in the testing of the plan in California this summer. That plan has gone through its fourth draft now, and it was table-top tested here in Washington this past spring and field tested in California. We just got the results of that, and there are essentially nine major findings of areas in which we need to really follow up and do some additional things.

Joe, I will let you address those.

Mr. WINKLE. All right.

Mr. Chairman, some of the things we found as a result of our exercise wherein we had 24 different agencies involved with about 400 people playing, were one, we want to take another look at our management structure that we have put together to deal with an emergency of this magnitude. Of course, the scenario would call for a major disaster declaration within hours, and there is a mechanism that we traditionally use. There is an appointment of a Federal coordinating officer to coordinate the overall Federal response.

We did find some cumbersomeness with the traditional way that we have dealt, and so we are readdressing that.

Also, with the group that would be at the Washington level, which is our coordination group of the policymakers of the various Federal agencies, we also want to readdress that. We would like to look and see if we could not streamline that particular body.

And our plan is designed around emergency support functional areas, and as a result of our experience in our exercise, we feel that we need to readdress these emergency support functional areas; possibly look at some consolidation as well as maybe some additional functional areas that we had not particularly anticipated, such as that connected with financial issues and the fact that banks probably would not be able to do business due to the fact of power outages and the electronic means by which banking is done today.

One other matter that came up was the business of the Federal Government liability, and we would like to address that front-end before we ever have to address it after an earthquake like this would occur.

The matter of public affairs; undoubtedly we want to look at how we can best deal with an overall, joint information network because of the interest that would be created worldwide.

And lastly, we want to look again at our logistical requirements to accommodate the mass Federal response that would be generated.

Senator GORTON. Thank you.

Senator Gore.

Senator GORE. Yes, very briefly, Mr. Chairman.

Dr. Speck, I did not get the name of your assistant there.

Could you identify yourself?

Mr. JOHNSON. Gary Johnson.

Senator GORE. Oh, that is right. I am sorry. Of course.

Could you supply a copy of the study to which you referred?

Mr. JOHNSON. No problem, sir.

Senator GORE. Fine.

I was really astounded by the number you used, and I have been sitting here reflecting on that, and I want you to elaborate just briefly on what exactly that includes.

The question in the study was what would happen to Memphis if a 7.6 on the Richter scale earthquake struck.

Mr. JOHNSON. As well as an 8.6 earthquake, Senator, the larger earthquake; and the figure I referred to related to the property damage loss relating to the larger earthquake, the 8.6 earthquake.

Senator GORE. And that would be just in Memphis?

Mr. JOHNSON. In Memphis, that is correct, sir.

Senator GORE. That would be a quake of the size which did occur in the New Madrid area during 1811, 1812?

Mr. JOHNSON. Yes.

Senator GORE. What would be the comparable figure for 7.6?

Mr. JOHNSON. Senator, I do not have that figure in my head at this point.

Senator GORE. But for the larger quake, $33 billion in property damage in Memphis?

Mr. JOHNSON. It is the controlling factor. I believe the total overall loss in the area came out to about $50 billion. So Memphis is clearly the significant area in our studies right now, sir.

Senator GORE. Just astounding

Now, Dr. Speck, what additional efforts should be made to prepare for the eventuality that a large earthquake could take place near Memphis?

Dr. SPECK. Mr. Chairman, Senator Gore, one of the things that we are focusing on with other agencies such as NBS and the Building Seismic Safety Council is the whole area of mitigation in terms of new buildings, in terms of retrofitting old buildings, and in terms of lifelines, and we are making some significant progress; but there is a great deal more to be done in this area.

We are just getting the results of work that has been done under a contract with the Building Seismic Safety Council in which they have balloted some 58 member organizations in respect to a resource document for model codes, developed the information that has to go into that, and we are in the process of moving to get that disseminated throughout the country.

The second area is the area of lifelines, and we recently signed a contract with the Building Seismic Safety Council to prepare a plan of action in respect to them. The ABE Joint Venture recently completed a similar plan dealing with existing buildings. A large

number of groups have to be involved if you are going to get these plans extensively implemented, and we would hope to have the lifelines plan completed within 18 months.

In addition to that, we are currently balloting the—and you can maybe speak to that more, Dick—we are currently having a balloting procedure of the Federal agencies in respect to an executive order dealing with mitigation standards, building standards, as it were, for Federal buildings, and the question there is going to be not only what are we going to recommend for Federal buildings, but what are we going to recommend beyond that for leased buildings or for buildings that Federal money is involved with in some way.

Senator GORE. Yes.

Dr. SPECK. So those would be some of the major initiatives that are actively under way in this area which is a critical area.

Senator GORE. Well, I look forward to following your efforts very, very closely.

I am glad that some work has already begun in Memphis, and I am glad the public awareness has been increasing as a result of the fine efforts that you and others have made. But clearly, in view of the results of this study soon to be released, 5,000 lives and $33 billion worth of property damage, we must devote even more attention and even more effort to making certain that everything possible is done to mitigate the consequences of such a quake and to deal with it should it occur.

So I want to thank you for your testimony.

Thank you, Mr. Chairman.

Senator GORTON. Senator Ford?

Senator FORD. I do not think I have any questions.

One thing that we talk about when discussing ways of saving lives is, what is the time span of warning when an earthquake begins? Is there any way to determine that, Dr. Speck? I know they are all different, and some are surprises and some you can make some kind of judgment, but is there any warning time that you might be able to give?

Dr. SPECK. I think I will turn to the Geological Survey on that. I know that if you listen to some other countries, they tell you if you know how to watch animals closely enough, the animals will tell you when one is coming.

Dr. PECK. As I mentioned, Senator——

Senator FORD. Well, we go by the moss on the trees.

Dr. PECK. As I mentioned, Senator, there have been some successful predictions, a few successful predictions of earthquakes based on a variety of phenomena, including the rate of swelling of the ground, the occurrence of flurries of small earthquakes, lateral shifting of the ground, and it is in looking into that sort of phenomena that we are doing very intensively in the Parkfield area of California.

But by and large, at this stage, for almost all earthquakes, we cannot predict an event. The earthquake waves themselves take some time to travel from one area to another. So for a distant earthquake, there could be a warning of a minute or so, but beyond that, no, Senator.

Mr. SPECK. Mr. Chairman, I might add that for that minute or so, it is not very significant when you are planning to evacuate and those kinds of things. You obviously do not have anything to plan against. Even a minute or so can be critical, however, when it comes to perhaps triggering valve closings on major pipelines and those kinds of things to prevent or at least reduce explosions. So even that much warning can be very critical in some areas.

Senator GORE. Would the Senator yield?

Just briefly, you mentioned the animal experiments in other countries, and the tendency has been to kind of laugh at that here in the United States, but I am told the Chinese do take that quite seriously and believe it has real utility.

We still do not understand acupuncture, and yet it works, and they pioneered that. Should we maybe re-examine our hidebound attitude about that and investigate whether there might be something to that?

Dr. PECK. Well, Senator, we are not that hidebound, and we have actually looked into it in some detail, looked into all the examples we could gain from our Chinese colleagues and what is in the literature. We have done some experiments ourselves, supported experiments on both behavior of monkeys and apes and that sort of thing, and cockroaches, even cockroaches. And by and large, we have not come up with anything.

After an earthquake, people remember all sorts of funny things: The dog howled, or chickens ran around in the yard.

It may work better in China because the people are so close to the animals and watch their behavior, and they enlist the help of millions of Chinese as part of a network, looking for premonitory phenomena. That itself may be a factor. But we have not come up with anything, although I will ask Dr. Filson to speak to the matter.

Dr. FILSON. We feel that there may be something here like, as you mentioned, acupuncture or folk medicine legend. There is usually a truth of a physical phenomenon behind it; we just have not been able to identify it, nor have the Chinese or any other foreign colleagues that work in this area. For several years, we ran a hotline in California and advertised an 800 number where people could call and record or put on record unusual animal behavior, and then we would try to correlate that behavior with the subsequent minor earthquakes in the Bay area. We could come up with no positive correlation.

We have looked at it. We are not very active in that area right now, but we continue to watch the progress and the experiments of the Chinese.

Senator GORE. That sounds like a mighty responsible approach. I appreciate it.

Senator GORTON. Thank you all very much. We appreciate it.

The second panel, Dr. Sozen and Mr. Flores.

Dr. Sozen, we have just received your written statement. The entire statement will be included in the record. Because of what you have obviously seen about time constraints, to the extent that you can summarize it, we would appreciate it.

STATEMENTS OF DR. METE SOZEN, PROFESSOR OF CIVIL ENGINEERING, UNIVERSITY OF ILLINOIS; AND PAUL J. FLORES, DIRECTOR, SOUTHERN CALIFORNIA EARTHQUAKE PREPAREDNESS PROJECT

Dr. SOZEN. Thank you very much.

I arrived in Mexico City on September 21, 2 days after the quake, at the request of Mr. Chung from the National Academy of Sciences, and a few days later other members of the Joint Team of the Earthquake Engineering Research Institute and the Academy of Sciences and National Science Foundation, and so forth, joined me, and we stayed there until last Saturday which I believe was the 28th.

I have my statements written to be included in the minutes. I think the facts have been very well described by the people who preceded me. If I may, I would like to render a few opinions.

Senator GORTON. Please.

Dr. SOZEN. From the viewpoint of structural engineering, of course, the most significant event in Mexico City was the peculiar nature of the ground motion. There were various things which were surprising. One was that the day I hit the deck, barely 48 hours after the earthquake, the records of the ground motion had been digitized and publicized and were available to all interested parties, which I think was the first time that I have ever seen it happen immediately after an earthquake. For comparison, I would like to mention that we are still to receive the similar records which were obtained in the Chilean earthquake which was in April. So the Mexicans are very well organized from that viewpoint.

The other thing that was significant was the steady state nature of the ground motion in that in one particular location in town, as I think it has been described before, the ground moved a total of approximately 18 inches back and forth at a very slow pace, once every 2 seconds. At another spot, only about 5 kilometers away from it—and I am still talking about the center of the town, the lake bed, the ground did the same motion in about 3½ seconds. This is very slow motion, not unanticipated, but it is still uncanny.

Now, another significant feature of this motion was that it went on for about 20 almost steady state repetitions, increasing its influence on buildings.

If you will allow me, let me show you a very naive model to explain what is going on at least from the viewpoint of structural engineering. We have talked about periods of buildings.

Senator GORTON. Yes; please explain.

Dr. SOZEN. Exactly. For example, when I push this little steel mass back and forth, it goes back at a certain rate, and in that case I would say it takes about half a second for it to complete one cycle. It is an analog for the period of a building. Even the building we are in would have a period, very low. It would do essentially the same thing, unfortunately.

Now, a high-rise building would have a longer period than a low rise building. Now for the ground motion that would occur most likely in hard ground in San Francisco, the ground would go back and forth—and I know it is an oversimplification—but at a speed

such as four times per second. It would be a very strong motion which would tend to excite the low rise buildings, the ones with the higher frequencies.

In Mexico, the motion was rather slow, and instead of exciting the low rise buildings, it excited the high rise buildings, and it did not only excite them, but it kept going on and on until their displacements were very large, so that if there was ever a problem with the structure or with its stability, it came up.

If I may switch over to a few slides, please, this is a rather hastily digitized version of one of the motions that was reported in town, and what I would like to draw your attention to is the distance between the crossings of the curve on the horizontal axis, or what we call the zero crossing rate, which kept steady for a very long time. If we try to interpret this in terms of high and low rise buildings, what I have there really is a sequential calculation of buildings which would be low rise and buildings which would be high rise.

Senator GORTON. The lowest at the upper left?

Dr. SOZEN. The upper left would be a very low building. The one that you see on the lower left would represent a building of, let us say, about 16 or 18 stories. And then on the upper right hand side again we go higher and higher.

What it attempts to say, and I concede that the slide is rather mediocre, is that this earthquake selected the buildings in the mid-rise section, from about 6 or 7 stories to about 17 stories, to excite.

Actually, what happened is that if you think of the vertical axis as a measure of the damage potential of the earthquake and the horizontal axis as an indication of where a particular building would be in relation to its period, for example, if you start out with, say, a 10-story building having an initial period of 1 second, it would be mildly excited by the earthquake, and then as it was excited, it would crack or it would yield, and its stiffness would decrease, its period would increase, and as its period increased, then the demand of the earthquake on the building would be higher, and then we would have the tragedy.

Now, what is I think important is that Mexican engineers knew this. What I show you there as a solid line is the design response spectrum for the soft parts of the city. What is shown there as a broken line is the response spectrum or earthquake effect that was actually measured. The two, of course, have been normalized, but there is no question I think in the minds of the members of the technical community that Mexican engineers anticipated this type of motion, and indeed, it was no different from what they obtained.

But I believe what they did not anticipate, and here I am speculating because I have not talked to every one of them, is demonstrated in this slide which compares a measure of the response to the earthquake. Now, the curve that you see there with a broken line is the response to one of our classic earthquakes, El Centro, 1940. It is an earthquake in Imperial County, CA. The solid line is the response to the Mexico City ground motion, and I think you will find that up to about 1½ seconds, the broken line is above the solid line, which indicates that our type of earthquake, or I should not say our type of earthquake, the earthquake that you would have on hard ground would really demand a higher energy from

the structure, but once you go to the right, you find that the Mexican motion peaks way beyond one's expectations.

Now, hindsight sets in very quickly in our business. Once something has happened, then it is very easy to predict it. I think I will confess to you now as a member of the structural engineering community that I would have found this comparison very hard to believe before it happened. The amount of energy that this earthquake pumped into their high rise construction was I think at the extreme edges of the credible region, and I think that is probably the main lesson I have learned from this earthquake, that I find it easier to believe the extremes of credible events now than I did before, and because of it, to me—and I do not live too far away from St. Louis—the vulnerability of St. Louis and of Memphis is much less unreal now than they used to be before September 19.

Let me show you a few more slides about the situation. Of course, I was very much interested in their hospitals because I work on the Structural Safety Board of the Veterans' Administration. They had three hospital systems in the city of Mexico. They were all stopped because of events like this, and of course, it is up to us now to find out whether the vigorous program that the Veterans' Administration carried out to make sure that all their hospitals were safe and that we would not repeat the tragedy of 1971 again, is really founded on firm ground and that our methods would be able to, if I may say, retropredict this failure.

Now, about their codes, Mexico City has an excellent, rather sophisticated code. This is one of their 13-story apartment buildings. This was one of three units. This one contains 90 apartments. The other two did, also. The other two failed.

But you will see that this one was ready to fail. This is one of the interior columns of the building. And what I see in that particular case is that the movement of the building was very slow. This is an apartment inside that building in which things have not been disturbed, have hardly been disturbed. But because of the tremendously high forces created by the earthquake, the system came down.

I think their codes were quite competent.

But how well they were enforced I do not know. All I can tell you is that I looked at—and I know the exact number—57 residential buildings very carefully that were still standing up. Some had architectural damage, some had minor structural damage, but in no case did I see a building that I would dismiss as being substandard construction or having substandard materials.

My immediate reaction to all this is that there is a tremendous amount of information in terms of data to be acquired from this. The Mexicans do not know and we certainly do not know how their foundations behaved. As it was indicated, we have a 21-story structural steel building, which is supposed to be the indomitable system of earthquake engineering, on its side. It is essential to know why it came down.

As you would very well know, looking is not seeing. We have to do a lot of work in order to be able to appreciate what happened, and of course, we do not have to do anything at all, but the sooner we do it, I think the better it will be for our public safety.

I think I will stop here.

[The statement follows:]

STATEMENT OF METE A. SOZEN, PROFESSOR OF CIVIL ENGINEERING, UNIVERSITY OF ILLINOIS, URBANA-CHAMPAIGN, IL

SEPTEMBER 1985 MEXICO EARTHQUAKE AND ITS IMPLICATIONS FOR RESEARCH RELATED TO PUBLIC SAFETY

The main shock of the 19 September 1985 Mexico Earthquake occurred at 13:17:47.6 GMT (7:17:47.6 a.m. local time in Mexico City) and was rated to have a Richter magnitude of 8.1 (Ms).

The epicentral region has been located near a small town, Lazaro Cardenas, on the Pacific coast of Mexico in the State of Guerrero. The distance from the epicenter to Mexico City was estimated to be approximately 400 km. Using aftershock data, Dr. James Brune of the University of California at San Diego estimated the rupture to extend approximately 200 km, with Larzaro Cardenas near the middle of the rupture zone. As well as progressing northwest and southeast from Larzaro Cardenas on the surface, the rupture penetrated obliquely under the landmass of Mexico. An earthquake related tidal wave (Tsunami) with a height of less than 2 m was observed on the beaches around Lazaro Cardenas.

Strong motion measurements

The Guerrero accelerograph array, which was in the process of being installed as a joint project of UNAM (National Autonomous University of Mexico) and UCSD (University of California in San Diego) already had 20 of the intended 30 stations in place. A total of 18 of these stations produced strong motion records. Measured peak accelerations in the epicentral region were approximately 0.15 g and the duration of shaking with accelerations not less than 0.1g exceeded 10 sec.

The institute of Engineering of UNAM maintains a network of approximately a dozen stations to measure strong ground motion in Mexico City. All of these stations are reported to have produced data. Jorge Prince of UNAM made reduced data available to interested professionals one day after the main event. In general, the strong motion measurements in the metropolitan area indicate first that the intensity of the earthquake in those parts of the city away from the old lake bed was very small. However, within the central portion of Mexico City, which is founded on a dried lake bed, the motion was measured to be 0.2 g or approximately five times as large as in the outlying districts of the city. Another important characteristic of the ground motion, reproduced in Fig. 1 for one of the accelerograph sites, is its steady pace. At the site, the ground moved a total distance of approximately 16 in. completing each cycle in 2 sec. The steady nature of the ground motion exacerbated its influence on moderate rise construction.

Figure 2 provides a preliminary measure of the intensity of the motion obtained at SCT, Mexico City. The velocity response spectrum for that motion is compared with the response spectrum for a well known U.S. strong motion record, El Centro 1940 N. While the spectral velocity for El Centro 1940 exceeds that of SCT 1985 up to approximately 1.5 sec, at higher periods the motion at SCT has a considerably higher velocity response.

Figure 3 provides a crude and relative measure of the story displacement of buildings with different periods. It may be assumed for a preliminary assessment that the fundamental period for a given type of building varies with height. Ratio of the calculated linear single-degree-of-freedom displacement to the period than may be used as damage indicator. From Fig. 3 it may be concluded that low-rise buildings (with low periods) would not be excited by the motion measured at SCT while building with effective periods around 2 sec. (moderate-rise buildings) would be susceptible. The same conclusion may be made from Fig. 4 which shows the maxima for Fig. 3 plotted against period.

The idealized theoretical trends shown Figs. 3 and 4 were confirmed by observations of the behavior of actual buildings. In connection with the evaluation of the safety of buildings in which U.S. Embassy and Consulate officials lived, I investigated the state of 57 residential buildings in Mexico City. The group up to five stories, which represents buildings with low periods, had hardly any damage. The group from 7 to approximately 17 stories included buildings with very heavy architectural damage, some with light structural damage, and some with foundation problems. In general, it can be said that moderate-rise buildings were more vulnerable to the type of strong ground motion experienced in the center of Mexico City than low rise buildings.

Structural damage

As it has been widely reported, structural damage to buildings within the lake bed region was severe. As many as 1,000 structures may have been very severely damaged or destroyed. In general, this group included buildings ranging in height from 5–21 stories. Casualties may have approached 10,000.

When I was in Mexcio City, there were many rumors circulating that much of the damage was due to poor quality materials or substandard construction. I can say that in my seven-day survey of the damaged and undamaged areas, I did not come across any moderate or high-rise building, standing or destroyed, that I would dismiss as a building with blatantly substandard material or design. Systematic inspection and tests may reveal such cases in the future, but it is unlikely that more than a very small fraction of the buildings constructed in the last two decades will be found to be substandard.

There were some threads of common attributes that Ed Johnson (Atkinson, Johnson, and Spurrier of San Diego) and I could observe in the buildings that were destroyed or severely damaged. One of the general problems was the relatively high flexibility of the buildings caused by the slender proportions of the girders, span lengths, and (sometimes) column size. The fact that in many structures there were progressive reductions in column size with height from base gave me the impression that the designers, presumably staying within the requirements of the Building Code, were doing their best to economize.

In a few cases, I noticed that the amount of transverse reinforcement used in their columns was less than what would be required by building standards used in the United States for earthquake regions.

Another apparently frequent source of collapse was the fact that the first story of the building was more flexible than the upper stories because of the necessity of accommodating a garage or stores in the first story.

A recurrent cause of damage in the upper stories of buildings was the construction of buildings of different heights next to each other with a seismic joint or space in between the two buildings that appeared not to be adequate for the nature of the earthquake that was observed. As implied above, the low rise and/or colonial type construction was not necessarily due to its strength but due to the fact that the ground motion did not excite low rise structures.

Critical damage due to foundation movements still needs to be evaluated. It is not to much of an exaggeration to claim that virtually no building in the lake region of Mexico City is currently standing exactly as it did before the earthquake. There were several instances of buildings leaning out of plumb from 10 to 15 deg. with the vertical.

There was an inventory of buildings that survived the 1957 earthquake with some damage. Some of these had serious damages during the 1985 event.

Ixtapa, a town near Lazaro Cardenas, is reported to contain several modern buildings severely damaged. Structural damage is also reported in the States of Jalisco and Michoacan.

Schools and hospitals

In our survey of the city, we observed problems with three school buildings. One had a total collapse and the other two had partial collapses. For the two with relatively heavy reinforced concrete construction, it appeared again that architectural requirements had made them flexible so as to put them into the vulnerable range of periods in relation to the earthquake motion. One of the school buildings, near the Tepito district of Mexico City, had very slender walls which had clearly overturned.

I have been told that Mexico City had three main hospital systems: The Juarez Hospital, the General Hospital, and the IMSS or Social Security Hospital. During the first week after the earthquake, none of the systems was in full operation. There was a very serious failure of a 13 story building in the Juarez Hospital. The General Hospital had suffered two serious failures, collapse of the seven story Obstetrics building and the 14 story Intern dormitory. The Social Security System had also serious partial collapses in their Medical Center and in the Children's Hospital.

According to my information the patients who had survived found adequate space elsewhere in the city.

Power systems

According to the informtion compiled by Luis Escalante (Los Angeles Department of Water and Power), the National Power Generation and Transmission System did not suffer significant damage. Distributional lines were damaged in various areas by collapsed buildings but power loss occurred only in the immediate vicinity of severe-

ly damaged buildings: Estimates effects to the distribution system within Mexico City were as follows:

Damaged transformers: 113 out of 26,000.

Poles affected: 50 out of 350,000 primary feeder lines.

Lines damaged: 6 km (3.7 miles) out of 10,500 km (6,520 miles).

Secondary distribution lines damaged: 10 km (6.2 miles) out of 15,750 km that is 9,790 miles.

Consumer connections out of service: approximately 15,000 out of three million two hundred thousand.

Water systems

According to Luis Escalante's information, damage to water systems occurred mostly in the distribution pipelines in the eastern and southeastern regions of Mexico City. It has been reported that an adequate conveying water from the south had been damaged.

Insufficient water flow and loss of water pressure affected three to five million citizens out of an approximate total of eighteen million citizens of Mexico City. The normal use of water per capita in Mexico City is 30–80 gallons per day. Immediately after the quake only 3–4 gallons per day per capita was available. By 25 September 1985, most private water cisterns were empty and many people were relying on tank truck deliveries to communities or purchases by container from itinerant vendors.

Propane gas

Propane gas sustems did not suffer significant damage. Collapsed buildings caused some gas leakage. The only reported major fire due to gas leakage was at the St. Regis Hotel. Gas from ruptured pipelines ignited and caused a major explosion.

Communications

Luis Escalante found that Telefonos de Mexico, the National Telephone Company, suffered major damage to its long distant telephone transmission equipment and heavy loss of life among its personnel when the top three stories of this five-story office building collapsed. All service to outside of Mexico City was lost. No estimate was possible about when the service would be restored. Telephone communications within Mexico City appeared to be completely operational.

Sanitation lines

Very little damage was reported to the pipes carrying sewage for Mexico City. The most likely areas where damage might have occurred would be where water distribution lines were damaged. Because sewage lines were inactive due to lack of water, thorough damage assessment could not be made by the relevant officials.

Transportation

No significant damage to streets and bridges within Mexico was found. Minor buckling of pavements was observed in the lake area due primarily to previous excavation in these areas.

Airports in Mexico City were not damaged and were operational the day after the earthquake.

IMPLICATIONS FOR RESEARCH RELATED TO PUBLIC SAFETY

The tragic experience of Mexico provides invaluable data for improving earthquake engineering construction and emergency response for the international community. To derive the optimum benefit for avoiding futrue catastrophes from this experience, certain projects ought to be implemented as soon as possible.

Ground motion

Thanks to the University of California-San Diego/National University of Mexico network in the epicentral area, this earthquake has yielded the richest collection of strong motion data ever obtained from the movement of a subduction type fault. Also, because of the strong motion accelerograph network maintained by the National University of Mexico, we have a reasonably good idea of the types of strong motion observed in the city. Analyzing the information in order to understand the nature of the rupture phenomenon and the attenuation and amplification phenomena would help improve our ability to estimate strong motion significantly.

Foundations

Because of the confusion created by rescue efforts, it has not yet been possible to make an orderly investigation of the contribution of foundation failures to building failure. It seems to be urgent to establish the possible causes and instances of foundation failure and to relate the overall building behavior to amplification studies.

Reiforced concrete construction

Much of the damage in town occurred in reasonably modern or recently built reinforced concrete construction. The specific causes of failure must be understood in order to avoid similar catastrophes in the United States.

Damage to steel construction

Mexico City was the seat of failure of a modern structural steel 21 story building. Because cities in seismic regions of the world have a significant amount of structural steel construction in this level, it is essential to establish the causes of failure of this building and to make necessary improvements in specifications.

Building code enforcement

It is well known that Mexico has a building code that would be considered to be one of the best in the world. The relationship between the building code and the actual buildings needs to be investigated.

Essential facilities

Most hospital systems in the United States, notably the Veterans Administration system, have been very carefully evaluated for earthquake resistance. It is therefore hoped that a similar disaster would not befall the U.S. system again as it did in 1971. Nevertheless, it would be of great importance to study the methods which have been used in evaluating the VA and other hospitals in relation to the failures that occurred in Mexico City.

Emergency

It would seem that hundreds of lives might have been saved in Mexico City if the correct equipment and experienced people had been available. Thinking the extremes of possibilities, it is important to test whether in our major cities, especially in those such as St. Louis and Charleston, we have the capability to lift heavy slabs in a matter of hours in order to save survivors of building collapses.

Evaluation of existing buildings

The failure of buildings constructed before 1957 and of the relatively new hospital buildings emphasizes the current state of the knowledge and performance on building safety evaluation. In view of the large inventory of buildings constructed before modern codes in seismic areas of the world, it would seem proper to reinforce the research and development effort in the area of strength evaluation, a task considerably more difficult than design and construction of new earthquake-resistant buildings.

CONCLUSION

The 19 September 1985 tragedy of Mexico has many dimensions that will come into focus as the data settle. However, one conclusion from it seems clear and dominant even at this early date after the event. Mexico City was subjected to a ground motion with an intensity beyond the extremes of the anticipated intensity. We must be prepared for the extremes of the expectable. Vulnerability of cities such as St. Louis, Memphis, and Charleston have become less unreal since 19 September 1985.

ACKNOWLEDGEMENTS

Much of the data reported were obtained and/or confirmed by members of the first group of earthquake professionals dispatched to Mexico City after the earthquake jointly by the National Academy of Sciences, the Earthquake Engineering Research Institute, American Society of Civil Engineers Technical Committee on Lifeline Earthquake Engineering, the National Science Foundation, and the Seismic Qualification Utilities Group. Members of this group were: Dr. James Brune, Specialty: Seismology; Mr. Edwin Johnson, Specialty: Structural Engineering; Dr. Ellis Krinitzsky, Speicalty: Geotechnical Engineering; Mr. Paul Flores, Specialty: Social Sciences/Emergency Response; and Mr. Luis Escalante, Specialty: Lifelines.

I am indebted to Ambassador Gavin and his staff at Mexico City for their generous and efficient support of the activities of the survey group.

Members of the Engineering Institute, National Autonomous University of Mexico, esepcially Jorge Prince, Luis Esteva, and Emilio Rosenblueth, cooperated fully with the survey group. Their cooperation was crucial to the success of the mission.

Preliminary (manual) digitization and response calculations were made by Sharon Wood, Ricky Lopez, and Marc Eberhard, staff members of NSF Project ECE 84-18691.

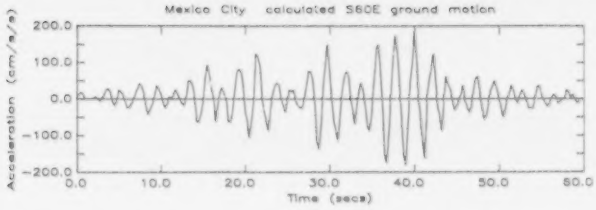


Fig. 1 S60E Component of Ground Accelerations Determined from N and E Components Measured at SCT in Mexico City (Near Intersection of Xola and Universidad)

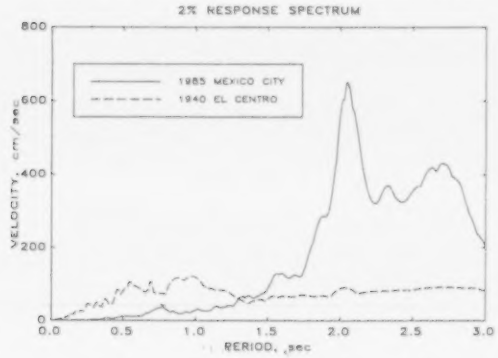


Fig. 2 Comparison of El Centro 1940 N Velocity Response with that for the Record Obtained at SCT, Mexico City, 1985, S60E Component

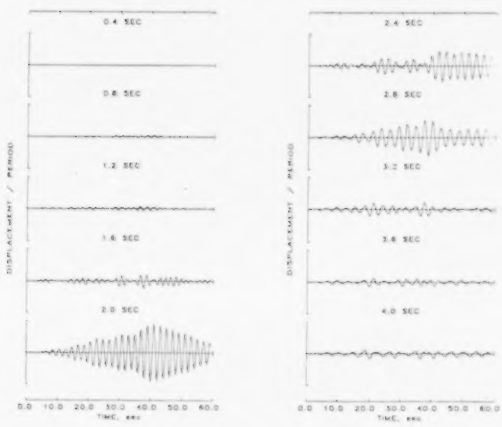


Fig. 3 A Measure of Drift Response for the SCT Motion (Damping Factor 2%, S60E)

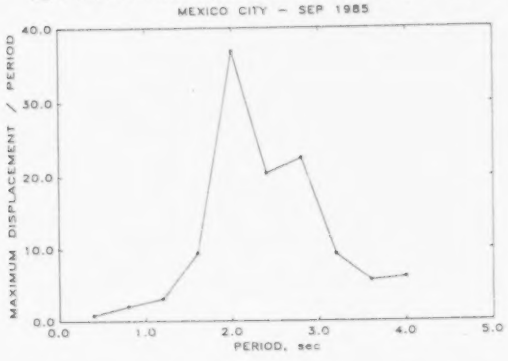


Fig. 4 Variation of Maximum Response Displacement / Period with Period for the SCT Motion (S60E, Damping Factor = 2%)

Senator GORTON. Thank you, Doctor.

Mr. Flores.

Mr. FLORES. Thank you, Mr. Chairman.

I was also part of the same team that accompanied Dr. Sozen. I was to look at and observe the emergency management aspects of the disaster as well as the societal response.

I would like to make some reference to a report issued in 1981 by the National Security Council and the Federal Emergency Management Agency that indicated that California was woefully unprepared for the consequences of a catastrophic earthquake impacting one of its metropolitan regions.

I think a similar assessment could probably have been made of Mexico City, but obviously their time right now is September 19 and 20. Certainly socioeconomic conditions there made preparedness efforts more difficult to carry out.

For purposes of this hearing, I would like to provide your committee an initial assessment of the Mexico City earthquake disaster by discussing the areas of hazards reduction in preparedness, emergency management and reconstruction, and identifying some implications for the United States.

Regarding preparedness, I think programs to educate the public in Mexico were in need of greater support before the quake. The department established to develop such programs was cut by the current administration for austerity reasons most likely. I think the implication for us is that public education and information programs underway in the United States are raising the overall awareness of the population, but I think there are some next steps, and these should be toward mobilizing preparedness and self-help at the community level, which will be more difficult to do. These next steps will be more complicated and will require greater commitment on the part of government and community leaders.

As far as hazards reduction programs, in all fairness to Mexico, programs of these types are difficult to design and costly to carry out, but there is no question that such programs in the aftermath of a catastrophic earthquake prove to be cost effective.

Mexico now faces billions of dollars' worth of physical losses and staggering social losses in human lives, suffering, and disruption to the conduct of their social affairs.

In the United States, hazard reduction programs are only in the developmental stages, with only a few local jurisdictions actually having some programs in place. These programs can be a costly burden to local government and must be supported by the States and the Federal Government directly with financial assistance, or indirectly through incentives.

As is the case in any large metropolitan area exposed to seismic risk, the appropriate level for preparedness action is the local level. Even though Mexico City may be considered to be administered or managed by the national government, in the final analysis it is not much differently administered than most of our own metropolitan areas.

Local governments must be provided more support to carry out long-term hazards reduction and preparedness programs and should be more involved in directly planning such programs. Given

the complexity of our large metropolitan areas with many autonomous jurisdictions within an urbanized area, perhaps a regional approach would be appropriate.

Regarding emergency response, Mexico City's response was exhilarating on the one hand and extremely problematic on the other. Search and rescue efforts in Mexico City took some time in getting organized. Whether or not a faster response would have saved more lives is a question that merits further study, but there is no doubt that the number rescued in the immediate hours after the earthquake was due to the tremendous response of the public itself. There were many heroes in those hours.

But a critical period was reached in the search and rescue effort when organization and technical expertise were of the utmost necessity. Mexico is not alone in its need for more effective methods of urban search and rescue. In the United States, we too need dedicated special training programs to upgrade our capability in that emergency response function.

During the Mexico City disaster it was evident that a multidisciplinary team was required for expeditious rescues to be made. Engineers, medical and fire personnel should have been working together as a team as the efforts to rescue victims alive became more critical. The experience in Mexico City provides us here in the United States with the necessary base by which to structure urban search and rescue training programs.

Damage assessment and communications in Mexico City also proved to be problematic. The importance of communications in managing an extremely large disaster is not only related to hardware, but just as importantly, it is related to the collection and processing of assessment information. Many decisions have to be made during a major disaster and should be based on the best information available at that moment. In Mexico City, even a few days after the earthquake, it was not clear that a comprehensive assessment had yet been formulated on which prudent decisions could be made.

Initial government estimates were underestimated, yet that did not have to be the case if better methods for collecting emergency information and estimating damage and losses had been in place before the earthquake occurrence. Utilizing such methods can be of particular importance when communications hardware fail.

In the United States, emergency information management systems are only at a proposal stage. Feasibility studies have been conducted and recommendations have been made, but such systems are yet to be built. A basic reason for not having the systems in place is cost, yet the costs of mismanaging emergency information could be staggering. Each metropolitan region in the United States should have an information management system in place that can integrate hazard analysis information, inventories of buildings at risk, and emergency management resources to utilize in the development of hazard reduction programs, in actually managing the disaster, and in planning reconstruction.

The Mexico City earthquake disaster, for us in the U.S. points to the need to develop better training programs based on what we learned from that tragedy. Urban search and rescue is only one area that merits further study for application.

The need to understand the seismic risk in our metropolitan regions is also important, but more important is the application of that understanding and knowledge in reducing our hazards and in improving our emergency management capability.

Regarding postearthquake reconstruction, the reconstruction in central Mexico City, the area most affected by the earthquake, will be a slow process. Mexico City is just beginning to systematically collect information on the consequences of the earthquake on its people, environment, and economy. This evaluation process will necessarily take time but hopefully will be completed before major decisions are made on how best to reconstruct.

This principle will be as important and applicable to the United States should we be faced with such a disaster in the future as it is to Mexico City now. Earthquake disasters of this magnitude also provide opportunities. Those opportunities that are in the public's best interests should be exploited, but only when tangible data is in hand and all the alternatives have been weighed. For Mexico City, necessarily moving slow may be an opportunity in and of itself.

In the United States we must learn all we can from how Mexico City reconstructs. We can also assist Mexico initially, not with pledges of millions of dollars for the physical reconstruction, but with lower cost research to determine the full implications of the disaster, both social and economic. Our own research efforts of this great disaster should be of a collaborative nature, assisting to the extent that we can with support to private and public research institutions in Mexico that recognize the need to study the impact of this disaster, so as to have a base for proposing sound alternatives to the problem of socioeconomic and physical reconstruction.

Thank you.

Senator GORTON. Mr. Flores, thank you.

Let me ask you a what if. If there were an earthquake in the metropolitan Los Angeles region which caused the same amount of physical damage as the Mexico City earthquake, would your organization, would southern California, be better prepared to deal with that from the point of view of its immediate postearthquake response, finding and saving of victims who could be saved and the like?

Do you have a plan in place there in southern California to deal with this kind of an emergency in a measurably more effective fashion?

Mr. FLORES. We do not have a plan per se. Each local jurisdiction must have its own plan in place. We do not have a regional plan, and we should, perhaps, of how those local jurisdictions must need to coordinate with each other. This year our particular project is addressing that issue, but it is a political one, getting local jurisdictions to work together with a common base. It is a difficult process.

But I do think that it is important. It is not enough to think that the State or the Federal Government will come in and solve all the problems. The major problems need to be solved by the local jurisdictions themselves, and I think greater effort needs to be put into that area.

Senator GORTON. Dr. Sozen, do you have any insight yet into how much this earthquake was simply an experience from which Mexico City and we must learn something with respect to the con-

struction and maintenance of buildings? How much of the damage that occurred could have been avoided with the building codes that were in place, and was not avoided either because the codes were ignored or not enforced?

Mr. SOZEN. I never got the feeling that their building codes were ignored, and I did say that their building codes anticipated this type of motion, but not its intensity.

Senator GORTON. So primarily what we have learned from this is that this kind of quake is likely to be much more intense than we had previously anticipated.

Mr. SOZEN. That is my general impression from my conversations with Mexican engineers before the event and after the event, that it was the intensity that they could not estimate.

As a matter of fact, if you look at the distribution of damage in the 1957 earthquake, its location with respect to the town and also the types of buildings which were damaged, you find that the damage this time was exactly in the same areas and exactly in the same type of buildings, only this time—and here it is my own opinion, it is not a scientific fact—the damage was about twice, maybe three times as intense because of the rather rare nature of what did happen over there.

And of course, from that I get a lesson which is really very important for us in that they did have some buildings which survived the 1957 earthquake but not the 1985 earthquake.

Senator Gorton. Why?

Mr. SOZEN. Well, it is very difficult to evaluate the resistance of buildings. It is much more, it is much easier to design a brand new building to be earthquake resistant, never earthquake proof, but earthquake resistant, than to look at an existing building and say what sort of an earthquake it will take. And I am afraid that is a place where we have to do a lot of work, and here is a very good, if tragic, opportunity in which we could improve our knowledge.

Senator GORTON. Thank you.

Senator Gore.

Senator GORE. Yes, just briefly, I would like to follow upon the chairman's questions about codes. Mr. Flores, you were quoted as faulting the enforcement of codes in Mexico City.

Mr. FLORES. I was?

Senator GORE. In the Washington Post, September 21. So let me just read it to you, and you tell me if it is wrong. "Mexico City has been working very hard to upgrade its building codes, but the codes are one thing, and having the codes applied in the whole construction process is something else."

Maybe I am reading that wrong, but I got from that the impression that you felt that the application of the codes was deficient even though the actual codes themselves might be adequate. Maybe I read into that word application enforcement, but do you want to tell me in your own words?

Mr. FLORES. Sure. I think that situation is just as a applicable to us here in the United States. The application of the code, the construction process, is very different than the design of the code itself. In California, for example, the Seismic Safety Commission felt that to be an important enough issue where they put out a

report emphasizing the importance of the construction process, of inspection, to ensure compliance.

So I think worldwide that is an important issue that needs to be looked at.

I do not have—I am not an engineer, and I do not have the necessary data to flatly say whether Mexico City is in some kind of fault as far as application of the code. I just think it is an important thing to look at.

Senator GORE. Yes.

Well, since this quake was so serious, should we then redouble our efforts to make certain that these codes we spend so much time designing are rigorously applied when construction actually takes place?

Mr. FLORES. I think that is a very prudent thing to do.

Senator GORE. All right, now, Dr. Sozen, I hesitate to get into this area, but will you just very briefly explain to me the difference between frequency and period?

Is "period" the word that applies to the swaying the building?

Mr. SOZEN. I am sorry. It was really my bad use of English. They are one and the same.

Senator GORE. They are one and the same? All right.

Mr. SOZEN. In effect. Except that one is the reciprocal of the other. If I say something has a frequency of four cycles per second, it means it has a period of one-fourth of a second.

Senator GORE. All right, now I understand. All right, fine.

Mr. SOZEN. That is what it is.

Senator GORE. Now, both words can be applied to both the buildings and——

Mr. SOZEN. And the ground motion.

Senator GORE. All right, I have it now.

Is there any way to predict the likely frequency of earthquakes in particular areas?

Mr. SOZEN. In Mexico City, certainly, but that is a very special condition, and in other parts of the United States, like San Francisco, St. Louis, and so forth, we do not have the same sort of periodicity, at least I should say we have not observed it before. It is more of a random motion. It is a mix of frequencies rather than a single one. But indeed, on a general basis we have a reasonably good understanding of what type of ground motion to expect in various parts of the country.

It is when that we do not quite understand.

Senator GORE. Now, in the New Madrid area, is there any way to predict the periodicity of quakes in that area? Is there a consistent periodicity?

Mr. SOZEN. First, I am really getting out of my area of expertise. I must qualify my remarks by saying that, but I expect that when the energy release comes from the New Madrid earthquake, the type of motion that we are going to see, say, in St. Louis or Carbondale, IL, is not likely to be the one that we saw in Mexico City. It will be a different collection of frequencies, and of course, we do not know enough because we really have not taken those parts of the country as seriously as we have California and Seattle.

Senator GORE. But that is a mistake, is it not?

Mr. SOZEN. It seems to me more of a mistake than it did before September 19, yes, sir.

Senator GORE. Thank you very much.

Senator GORTON. Thank you both very much. We appreciate your being here.

The third panel is Dr. Herrmann, Ms. Noson, and Dr. Johnston.

Dr. Johnston I understand has a plane relatively soon, so we will change our order and let him start.

And again, for all three of you, your written statements we have from you will be included in the record as if read.

Dr. Johnston, please proceed.

STATEMENTS OF DR. ARCH C. JOHNSTON, DIRECTOR, TENNESSEE EARTHQUAKE INFORMATION CENTER, MEMPHIS STATE UNIVERSITY; DR. ROBERT B. HERRMANN, PROFESSOR OF GEOPHYSICS, DEPARTMENT OF EARTH AND ATMOSPHERIC SCIENCES; AND LINDA NOSON, SEISMOLOGIST, GEOPHYSICS PROGRAM, UNIVERSITY OF WASHINGTON

Dr. JOHNSTON. Mr. Chairman, thank you.

It is a privilege to be here today, and I would like to make a few brief remarks, giving a local perspective on earthquake preparedness.

My home town is Memphis, TN, and there are some things, starting there, I have to say, in the initial stages, which will be very important for the future.

Let me start by pointing out a difference between seismic hazard and seismic risk. The two are not really synonymous. I distinguish them by the question, Can actions of people have any effect on the situation? Hazard cannot be lessened or increased, but risk can. In other words, the earthquake hazard in Memphis is an inheritance of geographic location, its proximity to the New Madrid zone. Since we cannot control earthquakes, we cannot change the hazard, but we can do a great deal about earthquake risk. In Memphis, the danger posed to the population can be substantially altered by a number of actions, most significantly, by improved construction and siting of buildings.

Now, in that regard, let me make the following very rough comparison between Memphis and Mexico City. Mexico City is a major city located near a highly active seismic zone that is capable of very destructive earthquakes. Memphis is a large city located very close to a moderately active seismic zone capable of producing very destructive earthquakes.

Mexico City is built on unconsolidated soil, the alluvial fill of an ancient lake bed, and that adds greatly to the seismic risk of the city. Memphis is built on the unconsolidated soil in the Mississippi River Valley, and that is an important additional seismic risk factor for the city.

Mexico City had incorporated seismic resistance requirements into its building codes. Many of its buildings survived the recent quakes with minimal damage. However, many older buildings and poorly constructed buildings either collapsed or suffered heavy damage. At present, Memphis has no seismic requirements in force in its building codes. Although it has many well-built buildings,

there are also many old and unreinforced masonry structures. No Memphis building has ever been tested by a major earthquake.

This comparison cannot be pushed too far. The destructive earthquakes recur along the segments of the Mexican seismic zone about every 30 to 50 years, and that is a much greater frequency than destructive earthquakes in New Madrid, central United States. The soil conditions for Mexico City are probably considerably worse than in Memphis, although Memphis is much worse off than, say, St. Louis, which has a lot of bedrock for construction. And in Memphis, a much higher proportion of Memphians live in relatively safe wood frame housing.

However, this comparison does illustrate that seismic risk in the United States is a fact of life, and it is not just for the Western United States.

Now, in my written statement, I name a number of actions that have really already been touched on here today—the Central U.S. Earthquake Consortium, the participation of the local emergency response agencies, and the State agencies. So let me skip to what I consider the most important development for the Memphis area, and that is the local building code initiative.

As was pointed out in earlier testimony, building codes are enforced locally. There are no Federal or State requirements of what goes into a community's building code. And communities in the Central or Eastern United States have not enforced seismic requirements in their codes.

Now, in Memphis, the Memphis and Shelby County Building Code Advisory Board in late 1984 created a special committee, and its charge was to formulate recommendations for implementing seismic provisions in the recently combined city and county building code. The chairman of the committee was Mr. Warner Howe, a professional engineer who currently serves as chairman of the Building Seismic Safety Council and is a former director of the National Institute of Building Sciences, and is a resident of Memphis.

The special committee's work is nearly complete, and a set of recommendations will be submitted to the advisory board this fall for consideration for adoption by the Memphis City Council in the near future.

Now, even though the formation of the special committee is only an early initial step, I believe it is of great importance. As the recent Mexican quake graphically showed, it is buildings that kill people in earthquakes. The recent FEMA study which has already been mentioned this morning found that for the smaller of its two earthquakes, one of magnitude 7.6 occurring in the daytime when people are out of the wood frame houses and into other buildings, the deaths could range from about 2,500 up to for the maximum earthquake, up to about a 5,000 figure. A significant part of this is that the study also estimated that about 26 percent, or almost a third of the total casualties, would be school children and teachers if the quake occurred during school hours.

There was an excellent study also by the Federal Government, Department of Housing and Urban Development, in 1974 that actually went a step further than this recent FEMA study in that it estimated how much you could reduce the casualties and building losses if seismic code provisions were implemented. The estimates

were that if seismic code requirements had been put in in 1970 and a major earthquake happened 50 years later, the year 2020, it could reduce deaths by 40 percent and building losses by 35 percent. This was with a strategy that required no retrofitting of buildings.

So the committee's work has placed a heavy emphasis on design of a practical, workable code. The major hurdle is to get the code adopted. For example, the committee has not recommended retrofitting at the present time. It is felt that you need to walk before you run. They also require a variable standard in that not all buildings are given the same requirements of seismic resistance. Buildings designated as critical or high occupancy structures would be held to higher code requirements than, say, warehouses, storage areas, and the like. In this fashion, we feel that a code can be implemented that is not overly restrictive, is not economicaly burdensome, and can be implemented, and as more and more older buildings are gradually replaced by new buildings designed to the new code, seismic risk in Memphis can be substantially reduced.

Thank you.

[The statement follows:]

STATEMENT OF ARCH C. JOHNSTON, ASSOCIATE PROFESSOR OF GEOLOGICAL SCIENCES AND DIRECTOR OF THE TENNESSEE EARTHQUAKE INFORMATION CENTER, MEMPHIS STATE UNIVERSITY

Mr. Chairman, members of the subcommittee, it is a privilege to be asked here today to give a few brief remarks about the state of earthquake preparedness in the United States in general and in the Memphis, Tennessee area in particular. In the wake of the Mexico City tragedy this question assumes an urgency that is generally lacking during more normal times. However, since preparedness must, by definition, be accomplished before rather than after the fact, it is the actions we take during normal times that are of critical importance. Such action is hindered by the nature of the earthquake threat: we must prepare for an event of poorly estimated proportions that will occur at some nebulously defined time in the future. But no one in this room today or in the nation at large should doubt that sooner or later a large U.S. city will be subjected to a large, destructive earthquake.

In this testimony I would like to address some preparedness measures that are taken at the local and state level in Memphis, Tennessee, where public awareness of, and concern about, seismic hazard is much below that on the west coast. I chose Memphis for this not only because I live there, but also because in a number of recent studies Memphis has been identified as the highest seismic risk city east of the Rocky Mountains. In this regard, consider the following comparisons with Mexico City:

Mexico City is a major city located near a highly active seismic zone, capable of producing very destructive earthquakes.

Memphis is a large city located very close to a moderately active seismic zone, capable of producing very destructive earthquakes.

Mexico City is built on unconsolidated soil—the alluvial fill of an ancient lake bed—which adds greatly to the seismic risk of the city.

Memphis is built on the unconsolidated soil of the Mississippi River Valley, which is an important additional seismic risk factor for the city.

Mexico City has incorporated seismic resistance factors into its building codes. Many of its buildings survived the recent quake with minimal damage. However, many older buildings and poorly constructed buildings either collapsed or suffered heavy damage.

Memphis enforces no seismic requirements in its building codes. Although it has many well built buildings, there are also many old and unreinforced masonry structures. No Memphis building has ever been tested by a major earthquake.

The above comparison cannot be pushed too far. Destructive earthquakes occur with much greater frequency in Mexico than we believe is the case for the New Madrid seismic zone. Soil conditions for Mexico City are considerably worse than in Memphis, although Memphis is much worse off in this regard than, say, St. Louis. A

much higher proportion of Memphians live in relatively safe wood frame housing. However, the comparison does serve to illustrate that seismic risk in the United States is a fact of life that cannot be ignored and that this holds true for regions other than the western U.S.

EARTHQUAKE PREPAREDNESS IN MEMPHIS, TN

There is a semantic difference between seismic hazard and seismic risk; the two are not synonymous. They are most easily distinguished with the question "can the actions of people have any effect on the situation?". Hazard cannot be lessened or increased but risk can. The earthquake hazard in Memphis is an inheritance of geographic location and is due to the city's proximity to the New Madrid seismic zone. Earthquake risk in Memphis is the danger posed to the population and can be substantially altered by a number of actions, most significantly, the improved construction and siting of buildings.

If we accept that a non-negligible seismic hazard exists for Memphis, it is then fair to ask what, if anything, is being done to minimize the risk. Prior to the 1980's the answer to this question would have been "absolutely nothing". This is not greatly surprising since the New Madrid zone has been very quiet this century compared to the massive earthquakes it produced in the nineteenth century. Earthquakes do not make themselves a part of the fabric of life in the central U.S. An excellent study on the earthquake risk in Memphis [the MATCOG Report] sponsored by the Department of Housing and Urban Development in 1974 has gone virtually unheeded by the city.

The state of preparedness in Memphis has improved considerably in the last five years through initiatives of the federal, state and, perhaps most importantly, the local Memphis government. The state established the Tennessee Earthquake Information Center at Memphis State University in the late seventies. One of its most important projects has been the implemenation of an Earthquake Education Center (EEC), one of three prototypes in the nation (the others are in Charleston, SC and Seattle, WA). These EEC's are sponsored by the Federal Emergency Management Agency. Their objectives are to actively involve citizens in earthquake preparedness projects and to generally elevate the public's awareness of the earthquake risk in their cities.

The Memphis EEC, beginning its third and final year of FEMA support, has made a marked difference. A city- and county-wide earthquake safety week was held for the first time in February, 1985 and proclaimed by both mayors. Significant preparedness projects have been developed with the public school system, a particularly vulnerable population, and with the Memphis hospitals. A large and increasing number of earthquake and earthquake-related stories are being reported in the Memphis media—television, radio and newspapers.

The unique and difficult problems created by the occurrence of a large earthquake are now recognized by TEMA (The Tennessee Emergency Management Agency), and earthquake response planning is now an integral part of their mission. TEMA has formed a statewide Seismic Advisory Panel to help guide their activities in this area. TEMA also actively participates in the Central United States Earthquake Consortium (CUSEC), an umbrella emergency response organization with membership from the seven states for which a large New Madrid earthquake would have the highest impact.

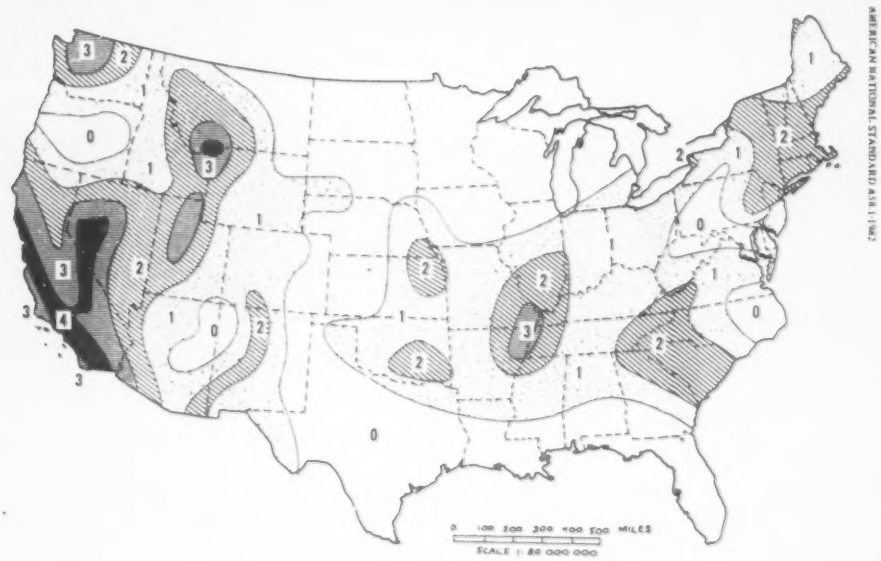
A LOCAL BUILDING CODE INITIATIVE

I will end my statement by describing what I consider the most important development of all in reducing the earthquake risk in Memphis. This was the creation by the Memphis and Shelby County Building Code Advisory Board in late-1984 of a special committee charged to formulate recommendations for implementng seismic provisions in the combined city-county building code. The chairman of the committee is Mr. Warner Howe, a professional engineer, who currently serves as Chairman of the Building Seismic Safety Council and is a former director of the National Institute of Building Sciences. The special committee's work is nearly complete and a set of recommendations will be submitted to the Advisory Board this fall. Consideration for adoption by the Memphis City Council is the next step.

Even though the information of this special committee is only an early, initial step, I believe it will prove to be of great importance. As the recent Mexican quake so graphically showed, it is buildings that kill people in earthquakes. The recent FEMA study by Allen and Hoshall, Inc. found that a major daytime New Madrid earthquake ($M>7.5$) would cause an estimated 2500–4000 deaths in Memphis. If the quake happened during school hours 26% of total casualties would be school chil-

dren and teachers. The 1974 MATCOG study concluded that implementation of strong seismic building code requirements in 1970 would reduce deaths by 40% and building losses by 35% for a major daytime quake in the year 2020. This was for a strategy that required no retrofitting of existing buildings.

The committee has placed heavy emphasis on the design of a practical, workable code fitted to the seismic risk of the region. Adopting the California code requirements, for example, is indefensible economically when the chance that a Memphis building will be subjected to strong seismic forces is much less than in California. The committee instead has allowed the degree of required reinforcement to vary according to the importance of the structure. For example, the attached seismic zoning map from the American National Standard Institute places Memphis in seismic Zone 3. instead of requiring all lateral strength computations to use Zone 3 values, a factory or warehouse would be allowed to use a Zone 2 or 1 designation, while critical and high occupancy structures would be held to Zone 3. In this fashion a code that is not overly restrictive nor economically burdensome can be implemented. As more and more older buildings are gradually replaced by new buildings designed to the code requirements, the seismic risk in Memphis can be substantially reduced.



Map for Seismic Zones – Contiguous 48 States

Senator GORE. Mr. Chairman, thank you for yur courtesy in letting me address questions to this witness out of order because I want to make sure that he gets his plane back to Memphis. I do appreciate it.

And Dr. Johnston, I appreciate your testimony and the opportunities we have had to work together in the past. In my opinion—it is a little biased because we are friends—I think you do an outstanding job, and I think your testimony again illustrates that fact.

You heard the testimony earlier from FEMA about this forthcoming study. How accurate do you believe that estimate is which he used of $33 billion and some 5,000 lives lost? Do you have any way of assessing it?

Dr. JOHNSTON. Well, Senator, I do not have any of my own figures. I am familiar with that report, a draft version, and I think those figures have been upgraded some from the draft version that

I am familiar with. That would be the worst case scenario of the maximum possible earthquake, 8.6, occurring during daytime school hours, I am sure. The likelihood of such an event is very low, but those worst case figures I would not argue with. They are based on a very extensive study.

Senator GORE. When you say the likelihood of that event is low, you prepared some estimates on probability which I would like to share with the committee and ask you to confirm.

The probability of an 8.3 earthquake prior to the year 2000 in the Memphis area you estimate to be as low as 1 percent; over the next 50 years, up to 4 percent; but when you get down to a 7.6-degree earthquake, the probability goes up to almost 9 percent before the year 2000, and almost 30 percent before the year 2035. The probability of a 6.3-degree earthquake on the Richter scale is as high as 63 percent in this century, 40 to 63 percent before the year 2000, and 86 to 97 percent before the year 2035.

How much damage would be done from a 6.3 earthquake in Memphis?

Dr. JOHNSTON. That would depend a great deal on whether it happened in the northern or southern portion of the New Madrid, which runs from northeast Arkansas up into Missouri. You can see that in terms of energy release. A magnitude 6.3 is nearly a thousand times less than an 8.3 because the magnitude scale is exponential. So you are talking about two quite different events, and I would emphasize that.

But a 6.3 can be quite destructive if it happens very close to a population center. The 1971 San Fernando earthquake was a 6.3-6.4, and it did over a half a billion dollars worth of damage and killed, I forget the number, close to 100 people. So if a 6.3 happened on the southern portion of the New Madrid zone, which comes to within about 35 miles of Memphis, it would be destructive in the city. It would not be a catastrophe, but it would be destructive, and there would be casualties and loss of life.

Senator GORE. All right.

Now, one of the things we need is better data. We need a better way to absorb and organize the data that we have.

How important in your view are the seismic data networks?

Dr. JOHNSTON. Well, as a seismologist, they are very important. They are really the basis, the core of all we do in understanding the earthquake process. We really talked about two different aspects of the earthquake problem here today: the basic research, understanding earthquakes themselves, and then the applied portion. Both are equally important, and one without the other is not going to be very effective. So for the basic earthquake research going on, the networks are the backbone of the process.

Senator GORE. What improvements could be made in the data networks?

Dr. JOHNSTON. Well, they are expensive. They have to run continuously, 24 hours a day, and you need a lot of stations distributed geographically to really pin down the earthquake occurrences. They generate a huge volume of data that is right now not centralized. It is not—I would have to say not fully utilized to the extent it could be. So I think a centralized data center would be very important.

And also, the networks really lead sort of a hand-to-mouth existence. The funding for them is not secure. It is distributed amongst a number of different agencies, and as one of the network operators, I would like to see long term secure and stable funding.

Senator GORE. Well, very good. I will close on that because my time has expired.

Mr. Chairman, I just want to note for the record that one of the most constructive actions we could take in response to the testimony we have heard today might well be to cause to stimulate some improvements in this seismic data network, and in particular, to improve our capacity to process the enormous amounts of data collected, organize that data a little bit better, and make it more useful to seismologists in their efforts to try to improve the predictions of earthquakes and earthquake damage.

But again, Dr. Johnston, I certainy appreciate your presence here today and hope you have a safe flight back to Memphis.

Senator GORTON. Thank you, Dr. Johnston We will excuse you now, with our gratitude.

Dr. JOHNSTON. Actually, I have a little more time, and I would like to hear the remaining testimony.

Senator GORTON. We would be happy to have you stay.

Dr. HERRMANN. Thank you, Mr. Chairman.

I would like to review the state of knowledge about and preparation for earthquakes in the Central Mississippi Valley. This region includes seismically active and potentially affected portions of about seven neighboring states within a 200 mile radius of New Madrid, which as we have heard before is the locale of the destructive earthquakes during the winter of 1811 and 1812.

I would like to point out that our awareness and concern about earthquakes in the area is not entirely due to the occurrence of those earthquakes in 1811 and 1812, as is evidenced by the locations of historical earthquakes. Even without the earthquakes of 1811 and 1812, we would still be worried about large earthquakes down in New Madrid. Large earthquakes have occurred in 1843 near Memphis and in 1895 near the confluence of the Ohio and the Mississippi Rivers. In addition, many other earthquakes have occurred in the area which have caused damage in the immediate vicinity of their occurrence.

The point I would like to make is that very large earthquakes have occurred in the region in the past 200 years, that the region is still seismically active, and that from our knowledge of geological processes, it is unwise to presume that we do not need to worry about large earthquakes in the future.

Fortunately, State and local governments are becoming aware of the earthquake threat and are beginning to prepare their response to the problem as a result of educational efforts of the U.S. Geological Survey and the Federal Emergency Management Agency. State agencies are preparing earthquake disaster response plans and are involving the Red Cross and other organizations in planning and training. Federal agencies such as the U.S. Nuclear Regulatory Commission, the U.S. Army Corps of Engineers, and the Veterans' Administration are taking steps to ensure the safety of the structures for which they are responsible. In addition, some of the newer buildings now being built have a seismic design element.

I will not dwell on the disastrous consequences of a recurrence of a major earthquake such as those of 1811 and 1812 primarily because a recurrence in the immediate future is not as likely as smaller but still damaging earthquakes. This judgment is based on an extrapolation of the activity rates of smaller earthquakes, and is open to possible error.

Our knowledge of the earthquake process is not as advanced as in California because the active portion of the fault associated with the New Madrid earthquakes is buried under 3,000 to 10,000 feet of Mississippi River alluvial deposits and cannot be directly examined. It is enough to say that such earthquakes would cause major damage in the cities of Memphis and in St. Louis, disrupt Mississippi River transportation, disrupt east-west transportation along interstate highways, and damage the many oil and natural gas pipelines passing through this portion of the Mississippi Valley which service in turn the major metropolitan areas of the Midwest and the east coast. In other words, a recurrence of the 1811–12 earthquakes would be a major disaster.

What we do anticipate with some confidence is a recurrence of an earthquake as large as the 1843 or 1895 earthquakes. Dr. Johnston has recently estimated that there is about a 50-percent chance that such an earthquake or an earthquake with magnitude greater than 6 would occur somewhere in the region in the next 15 years. This earthquake would certainly be smaller in magnitude than the magnitude 8.5 New Madrid earthquakes of 1811–12, but would still be large enough to cause substantial damage immediately near the earthquake itself, and depending where the earthquake would occur in the New Madrid seismic zone, would cause building damage in St. Louis or Memphis, depending, of course, on the nearness of the earthquake to these cities. There would be a substantial region of minor damage, such as broken chimneys, which would affect the occupants of thousands of homes.

I might mention that there was what seismologists would call a small earthquake in northern Kentucky in 1981, about a magnitude 5 earthquake. That caused several million dollars worth of damage primarily to individual homes with broken chimneys.

The results of extensive interdisciplinary scientific research during the past 10 years have been used to increase public awareness of the earthquake problem. However, the scientific input has the potential for being improved in the future. Improvements are required in the estimation of the ground shaking due to an expected earthquake. This in turn requires additional knowledge of the location and size of the expected earthquake, a better understanding of how the earthquake causes shaking at a particular point for given foundation conditions, and a better understanding of the recurrence rates of large earthquakes. These improvements hinge directly upon an ability to detect and record all earthquakes that do occur.

The result of dense monitoring near New Madrid since 1974 is best seen in figures 3 and 4, in which the locations of 2500 earthquakes are plotted. The significantly improved resolution due to a dense seismic network led to more precise locations and depths for the earthquakes. A set of linear fault segments are evident, which are not seen in the historical data of figure 1. While this is an im-

provement over the historical picture, much is lacking that affects our understanding of the earthquake process. Part of this is due to the very short history of dense observation in the central United States and part is due to the rate of seismic activity, which is lowerer than many parts of California. The low activity rate not only indicates a reduced earthquake threat, but also requires that our networks have to operate longer to fully understand the earthquake threat.

The need to consider the earthquake problem in the design of critical facilities is acknowledged, but the interests of Federal agencies change as the agency mission changes. We thus have the problem that many agencies want to use the data and research resulting from these networks but at the same time cannot contribute the long term support needed to maintain the required flow of scientific observations. The earthquake problem will not go away. The fact that it has a major impact on the estimation of geologic hazards guarantees this. This is indicated by an observation that 20 years ago little thought was given to the seismic resistant design of hospitals and power plants in the country, while today aseismic design is required for waste disposal projects not even thought of 20 years ago. We are continually running into geologic problems that require estimates of what is likely to happen in the next 50, 100, or 1,000 years.

Because the consequences of large earthquakes will affect the economy and defense of this nation as long as it exists, stable, continuous monitoring is essential

We are facing major problems with respect to our ability to monitor these earthquakes and to be able to learn everything possible about them. The problems are due to our ability to continue to acquire and analyze seismic data.

The first requirement that the scientific community would need is that we would require stable and long term monitoring of the seismic activity. The other requirement that certainly is needed is that our methods for estimating the ground motion due to any earthquake must be improved.

The Mexican earthquake points out the very disastrous effects of a large earthquake at large distances. The damaging effect of low level ground motion of long duration has not really been appreciated before. This will be even more of a problem in the central United States in which it is known that seismic waves are transmitted very efficiently over large distances.

Much emphasis in strong ground motion has been directed toward understanding the large motions near the fault itself, but little has been done to investigate the motions at large distances. In the Central United States, a research program stressing both theoretical and observational techniques is required in order to estimate more precisely the expected ground motion. At present, we have some approximate estimates, which have substantial uncertainty, which affects our ability to properly design structures to resist earthquakes and to assess the potential for earthquake losses.

In conclusion, much has been accomplished in the central United States in the last 10 years, especially despite essentially level funding in the earthquake hazard studies for the last few years. Much

more can be done by the scientific community in the future given modest improvements in our ability to acquire and analyze seismic data.

Thank you.

[The attachments referred to follow:]

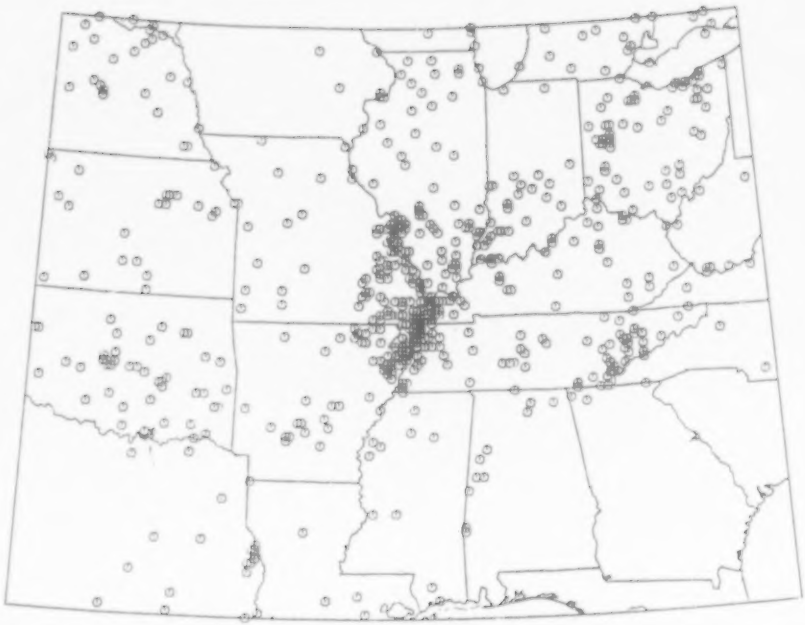


Figure 1. Plot of earthquakes large enough to be felt and reported in the Central United States since 1800. Damaging earthquakes have occurred near New Madrid, Missouri, Anna, Ohio, in the Wabash River Valley and in Kansas and Oklahoma.

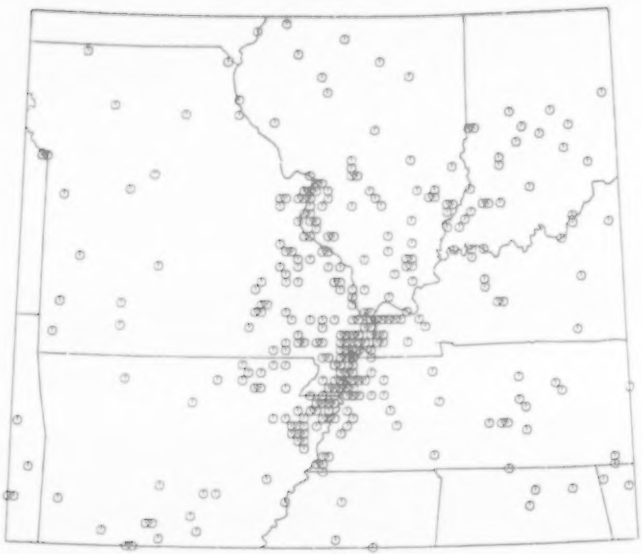


Figure 2. Expanded plot of historical earthquakes in the Central Mississippi Valley. The majority of historical Central United States earthquakes have occurred at these locations.

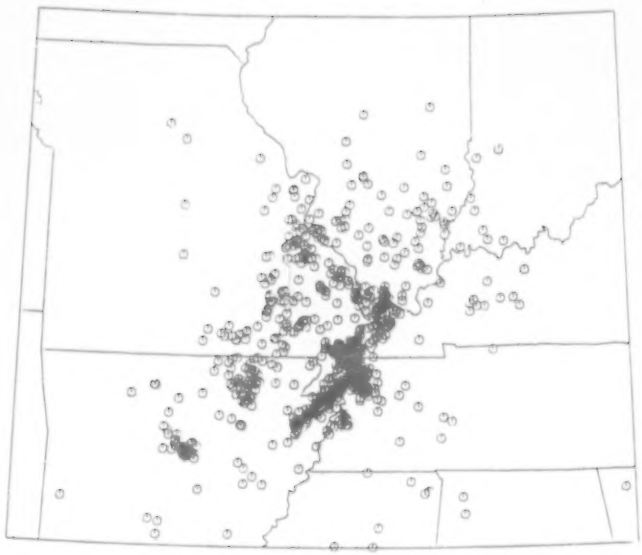


Figure 3. Earthquakes located using a dense distribution of highly sensitive seismographs operated by Saint Louis University, the Tennessee Earthquake Information Center, the University of Kentucky and other individual seismograph stations. Network operations are primarily sponsored by the U. S. Geological Survey and the U. S. Nuclear Regulatory Commission.

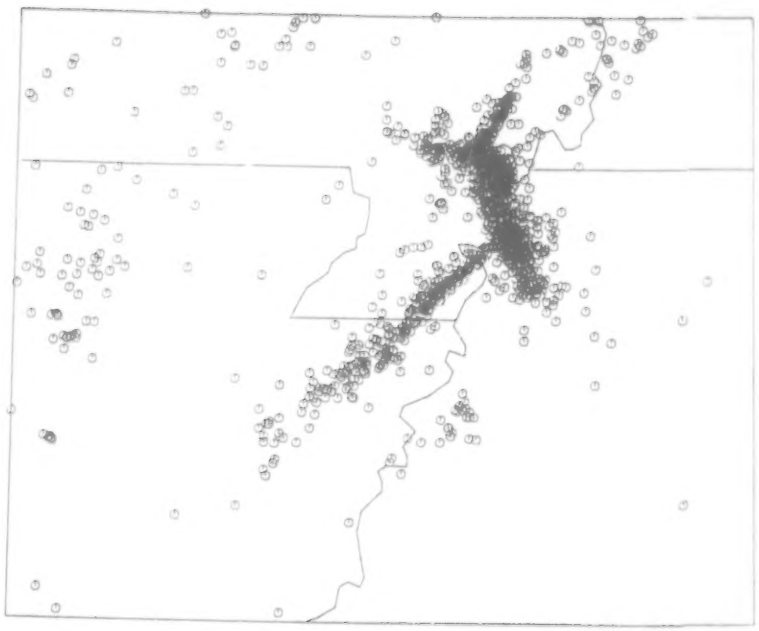


Figure 4. Expanded picture of recent earthquake activity. The Mississippi River and the Arkansas-Missouri and Tennessee-Kentucky borders are shown. Cairo, Illinois is located at the top where the Mississippi River runs into the map border while Memphis, Tennessee is located at the bottom of the map where the Mississippi River crosses the bottom border. Blytheville, Arkansas, site of a U. S. Air Force Base, lies directly above the seismicity pattern at the Missouri-Arkansas border.

Senator GORTON. Thank you.

Now, I should like to welcome my constituent, Ms. Noson, perhaps the one of the furthest traveled of any of the people here today, and we are happy to hear from you.

Ms. NOSON. Thank you.

I am Linda Noson, State seismologist, a position supported by the University of Washington. I would like to express my appreciation to this subcommittee for inviting me to comment on the implications of the recent Mexico earthquake disaster to earthquake hazards within the United States.

My experience as state seismologist combined with seismological and geological research activities has provided a unique opportunity to work closely with both the scientific community and those seeking to use the information from that community.

Sixty percent of Washington State's population lives within seismic risk zone 3, where major future earthquake damage is anticipated. The present delineation of Washington seismic risk zones excludes recent information on both earthquake data defining a major zone of shallow earthquake activity in southwest Washington, and also excludes potential damage from a greater than magnitude 8.0 earthquake off the coast of Washington, Oregon, or northernmost California similar to the September 19 Mexico earthquake that is currently being considered as a possibility.

Because of the exclusion of these two seismic source zones, the Washington earthquake damage estimates are extremely conservative. A much larger proportion of Washington State population must now be considered at risk. In addition, unlike the shallower activity in California, the earthquakes in the State of Washington, generally the larger damaging ones, have occurred considerably deeper and are felt over a much broader area. So similar to some of the activity in the eastern part of the State, we have a fairly large felt zone and affect a considerable area of the State when we have an earthquake.

The recent experience in Mexico underscores the extent of the human tragedy involved in an earthquake disaster. It is imperative to look closely at the situation to increase our own ability to prevent or reduce the effects of such a disaster within the United States. How well does the National Earthquake Hazards Reduction Program 5-year plan address the difficulties encountered in Mexico? It is my opinion that two elements of the National Earthquake Hazards Reduction Program plan closely related to loss of life in Mexico are precisely those that are most inadequately developed within the State of Washington.

First, collection, synthesis and communication information needed to better understand Washington earthquake hazards. The importance of the collection and synthesis of information to better understand and define earthquake hazards is illustrated by the structural collapse of structures in Mexico City within local pockets of high ground response. Even where information has been collected that could be used to develop Washington's site vulnerability maps, few efforts have been carried out to synthesize that data in a form useful to nontechnical users or to distribute the information to those responsible for its application.

The severe damage in Mexico City was unrelated to surface faulting and is a reminder of the importance of site vulnerability studies that extend beyond the identification of active surface faulting. Although dramatic damage can be caused by active surface faulting, most earthquake damage, even in areas like California with numerous active surface faults, is caused by ground shaking and its secondary effects.

Methods to define vulnerable sites need to be developed that include a range of parameters such as soil type, basement topography, depth of bedrock, and past Modified Mercalli Intensity history. Areas of higher relative ground response in Seattle, WA following the 1949 and the 1965 earthquakes were not related to simple distribution of geologic materials. Most importantly, ongoing procedures for information transfer need to be developed to communicate earthquake hazard information to building officials, planners, emergency responders, and other data users.

Two, the second area, preparedness planning and hazard awareness programs. These programs are both inadequately developed within Washington State and inadequately financed by the National Earthquake Hazards Reduction Program Plan. Development and implementation of State loss reduction strategies within areas only infrequently subjected to major earthquake damage is inhibited by a low perception and understanding by residents of what the hazards are and what steps can be taken to reduce their effects. It is necessary for State and Federal Government to provide direction in the form of policy development and well defined State program priorities.

Looking at the Mexico quake to explain the need for earthquake planning and specific steps to reduce one's vulnerability to those hazards, programs such as earthquake safety and education programs, these programs are needed both to explain to those people that must apply codes and enforce codes the necessity for that code development as well as steps to reduce their vulnerability to earthquake hazards, and included in there are more than just the vulnerability to structural hazards: loss of life in most U.S. earthquakes has commonly been caused by partial collapse or being struck by nonstructural elements or building contents, and those are relatively inexpensive areas to address in hazard mitigation programs.

Two, strengthening of existing structures prior to improved earthquake resistant design codes, 1960 in Washington State. In the 1949 earthquake, $25 million damage was done. Over half of that was to the state schools.

Initiation of hazard reduction focused on land use planning, development of nontelephone dependent emergency communications systems. One of the things that I felt I learned from the Mexico experience is hams are going to be overloaded in the demands that are placed upon them to respond to the communication needs. Our hams in our area, I have contacted them with reference to communication system commitments after an earthquake, and they are committed to almost every major agency available. So I think systems like schools and hospitals need to look at their own communication development.

Guidelines for earthquake preparedness planning tailored to meet the needs of local government, in translation and transfer of relative scientific information. This is particularly important again in the area of building codes. In the State of Washington there was an NSF study looking at unreinforced masonry buildings within historic districts, and it was found that in many cases codes were not being enforced in the upgrade of these buildings because of a lack of perception of the need and a real lack of understanding of how to go about that enforcement.

The sobering fact that most loss of life during the recent Mexico earthquake occurred within the first 5 minutes indicates the need to improve pre-event hazard reduction efforts. Certainly, further basic research on the fundamental causes and effects of earthquakes will improve our ability to forecast the where, how big, how often, and how damaging of U.S. earthquakes.

The experience in Mexico, however, underscores the importance of more effective use of the scientific information that has already been collected.

Thank you.

Senator GORTON. Thank you.

I would like to ask you one question, but to ask each of the other two doctors to respond to it briefly as well.

As you look at the Federal program, the national program, what element or elements in it have been most useful to you in your own studies, and where, at the other end of the scale, do you find it least adequate and most wanting?

Ms. NOSON. OK, I can start with the least adequate since I touched that rather thoroughly here. If you look at the funding levels for element 4, which is the preparedness planning and hazard awareness section, it represents less than I believe 10 percent of the budget, and that does appear to be an area of difficulty in helping people both be motivated to take steps and also to know and identify what those steps are.

Senator GORTON. Where has it been helpful to you?

Ms. NOSON. Where it has been helpful certainly in basic research, fundamental research and defining what the source zones for potential ground shaking in our State are, and that is certainly, the seismic network has been extremely important. As I mentioned, there is recent data that came right out of the increase in both seismicity and stations, they seem to flower together, around Mount St. Helens in which we were able to define a source zone previously unidentified, and that source zone of having a shallow potential 6.5 magnitude earthquake makes us pause and wonder, can we have such an event in a more populated area.

That is new information, and it does change how we are going to both develop codes and how we are going to respond.

So that fundamental research has been probably the most important for me in determining the likelihood and consequences.

Senator GORTON. Thank you.

Dr. Herrmann.

Dr. HERRMANN. That is a very difficult question, Senator.

I cannot really respond to that, mostly because of lack of knowledge of what is going on in the other programs. I was able to observe Response 85, the earthquake response exercise that took

place in June, this summer, in San Francisco in response to a potential southern California earthquake, and I was quite impressed in reading the preparatory documentation, all the work that had gone into it and the scenarios they had for the training exercise.

I also realize that after the earthquake occurs, they do not really need a seismologist anymore because it is in someone else's area of expertise to worry about the response to the earthquake.

I think we certainly know more about earthquakes than we have in the last, let's say, 10 years ago, when the program was first started. There is much more to learn. We still are at the infancy in our stage of being able to say that given an earthquake at this particular location, this is really what the ground motion would be at some other place. There are errors in ground motion estimates. Engineers like to talk about confidence within a few percent in what the ground motion is. Seismologists like to use another scale and say that, well, we are within a factor of two or so. That is a major difference for input to the design of structures.

I have seen the efforts of the U.S. Geological Survey and FEMA in getting together local officials in encounter sessions to encourage people to worry about it. The sessions that have been put together in the Central United States are bearing fruit. We have to remember that, as Dr. Johnston mentioned, that in this country each local community can pretty much do what it wants to. And so leadership by example that is required here rather than being able to force anyone to do anything.

All in all, there has been a big improvement, but we are still woefully unprepared to respond to an earthquake.

Senator GORTON. Thank you.

Dr. Johnston.

Dr. JOHNSTON. Well, I would just add to that that I think our understanding of the earthquakes that occur away from seismic zones like Mexico and California, which is the case in the Central United States, is a major problem. Our understanding is much less than for those types of seismic zones, and most of the effort is going into the plate boundary zones. Now, that is hard to argue with because the seismic risk is higher in those areas, but we do need a major improvement of our understanding of these midplate, midcontinent earthquakes.

Senator GORTON. But take the other half of my question.

Where are you reasonably satisfied with the national effort, or where has it done the best job?

Dr. JOHNSTON. Well, I think that the effort to understand the fundamentals of the earthquake process has been well supported in the past. And this support seems to be constant and ongoing. So most of, I would say, above 90 percent of the really dramatic progress all the way back to the 1960's and the plate tectonics revolution, is the result of Federal Government support.

Senator GORTON. Thank you all very, very much for coming, each of you from some considerable distance, to help us in an extremely serious and real challenge. We appreciate your help.

Our last panel includes Mr. Haber and Mr. Bragg. We are going to hear from Mr. Bragg first.

Both of you have sat here patiently for a long time, though I hope an interesting one. As you can see, we are well past our aim

for a closing time. In each case, your formal written statement will be included in the record. If you can summarize it, it will be appreciated.

Mr. Bragg.

STATEMENTS OF JEFFREY S. BRAGG, ADMINISTRATOR, FEDERAL INSURANCE ADMINISTRATION, FEDERAL EMERGENCY MANAGEMENT AGENCY; AND JEROLD M. HABER, MANAGER, HAZARDS ENGINEERING DEPARTMENT, NATIONAL TECHNICAL SYSTEMS

Mr. BRAGG. Thank you, Mr. Chairman. I will summarize my comments and submit written testimony for the record.

I am pleased to be here with you this morning to present some personal thoughts and observations on the earthquake insurance issue. In 1981 FIA completed a study entitled "Earthquake Insurance: A Public Policy Analysis." Now, I believe that my fellow panelist will review that study in more detail, but one of the conclusions that we reached as a result of that study was that Federal intervention at this time in the earthquake insurance issue would hamper progress that could be made by the private sector. The study noted that there was an availability of earthquake insurance, but that there was a significant failure to purchase the product. It was suggested in the study that the Federal Insurance Administration do more to support public awareness of the earthquake insurance crisis, but that leadership for this issue should come from the private sector.

For the past 4 years the Federal Insurance Administration has attempted to implement that conclusion. We have encouraged the industry not only to market earthquake insurance protection, but also to suggest ways that an effective partnership may be created between the private sector and the Federal Government. The industry, due in large part to its marketing efforts, now has greater market penetration in earthquake insurance than ever before in the history of the country, but the industry is alarmed that as its penetration increases, reserves to meet its financial obligations become increasingly inadequate.

So the question has shifted now from one of availability, which in 1971 and 1981 studies and can be answered now in the affirmative, to questions of market penetration and industry capacity.

Most in the industry now believe that future market penetration will impair its ability to meet obligations in the event of a catastrophic earthquake, while on the other hand, a failure to provide broader protection could leave hundreds of thousands of people unprotected. Compounding the problem is the fact that courts are now interpreting policy language in much broader terms than either actuaries or underwriters had ever intended, and earthquake insurance is now required to be offered to all homeowners and residential policies in the State of California.

Finally, I should point out that current Federal measures are not adequate to assist the public with losses not covered by insurance. Additional disaster assistance payments may not adequately compensate victims and could at the same time create an extensive and unnecessary drain of Federal funds.

On the other hand, a realistic insurance approach has several advantages over disaster assistance payments. First, insurance with reasonably accurate rates could create a financial incentive for property owners to minimize the risk. Second, insurance provides more certain reparation than relief measures currently do. And third, insurance allows each property owner to purchase the precise level of insurance protection he would desire.

Unfortunately, however, current proposals to deal with the insurance and earthquake question are either unacceptable to various segments of the insurance industry or involve an unnecessary increase of Federal intrusion into this area.

As Administrator, I have encouraged the industry to review the proposals that are being circulated, and hopefully to draw positive conclusions from each of them. Hopefully they would be able to construct a solution to meet the needs of the public and to utilize, to the extent possible, the private delivery mechanism.

To date, there are about three proposals being circulated within the industry that are designed to meet this crisis. One of them is Federal reinsurance. Another one would be a Federal reinsurance corporation. And the third proposal is revisions to the Federal Disaster Assistance Program.

I would like to take each of these and just briefly describe how they would operate as the proposals are currently being circulated.

Federal reinsurance would act very similar to the original Riot Reinsurance Program. It would provide financial backup in the event of a catastrophic loss, but it would also include extensive Federal oversight of the reinsurance mechanism. Another major problem with creating simply a Government reinsurance program is that it would have the effect of supplanting the private reinsurance market which could, which would want to, and which could be expected to play a significant role in any earthquake insurance proposal.

It is largely because of that latter reason that the Federal Reinsurance Corp. concept has been presented within the industry, largely being supported by the reinsurance industry. Under this proposal, the government would create a Federal Reinsurance Corporation which would be tax-exempt, federally charge, quasi-public corporation to provide excess reinsurance for earthquake catastrophes. The corporation would have authority to borrow from the Federal Treasury, but under the proposal, a primary layer from the private reinsurance market would have to first be purchased before anybody could purchase a second layer of coverage from the Federal Reinsurance Corporation.

This proposal, like many of the others, still has some significant problems that need to be worked out. For example, how would insurers be encouraged to participate to the maximum extent possible under the program? What criteria and qualifications should be placed on foreign reinsurers to prevent primary insurers from purchasing underrated reinsurance which potentially could prove inadequate, only so that they could become eligible for the Federal program? What would the relationship be between a Federal earthquake catastrophe reinsurance corporation and other government insurance or disaster relief programs? And finally, would the rein-

surance be limited to property damage or include other coverages as well?

The final proposal that is currently being circulated in the industry is one which divides earthquakes between a class 1 and class 2. Under the scenario, a class 1 earthquake is one which would be within the financial capacity of the insurance industry to meet. A class 2 earthquake would be of such magnitude that the losses and damage to privately insured property would be in the many billions of dollars and would be outside the scope that the private insurance industry could be expected to pay damages.

Under the proposal, the dollar threshold could change significantly as the industry developed more surplus and reserves to meet their obligations.

The major objection to this kind of approach is that it would dramatically change the current disaster relief program from one of first dollar payments to one of more catastrophic types of coverages after the insurance industry had met as many of the obligations as they were financially able to meet.

I believe that many of these proposals could be amended to meet the objections of the conflicting constituencies. What I have noted, frankly, is a lack of such a commitment. We need an industry-wide commitment to consolidate the favorable aspects from each of these proposals. In my view, several expressed and implicit themes from each of the proposals should form the basis of an industry-wide discussion.

First of all, many perils which were once deemed uninsurable, namely, wind damage, homeowners coverages and health insurance, are now clearly insured by the private sector. The industry in my view should review liberally the extent of the coverage they could provide before calling upon any kind of Federal assistance to help them.

Second, to encourage participation in this type of program, disaster assistance should not be made available where private insurance is. The prospect of a disaster declaration with readily available Federal grants and loans would make efforts to sell earthquake insurance more difficult.

Third, participation in any insurance program should be voluntary. This does not preclude private market incentives, but the right of the individual to refuse the purchase and to bear the loss alone must be respected. Fourth, program development should include a risk bearing and administrative role not only for the primary insurance market but for the reinsurance market as well. Failure to incorporate all segments of the private insurance industry would be a failure to use their resources adequately and wisely.

And finally, any proposal to deal with this problem should be developed by the private sector and then presented to the administration and to the Congress for review.

As I stated at the beginning of my testimony, these thoughts really represent only my personal observations on this topic. We have not had time really to review it in detail with the administration, but I could commit to this committee that if a legislative proposal is developed along the lines that I have just outlined, I would be happy to present it to the administration for its review.

In the meantime, Mr. Chairman, I am available to work with you and this committee and the insurance industry on this difficult but solvable problem.

Senator GORTON. Thank you, Mr. Bragg.

Mr. Haber.

Mr. HABER. Thank you, Mr. Chairman, for the opportunity to speak here today.

In the 1970's under the auspices of the National Science Foundation we conducted a study of the nationwide loss potential from a number of different natural hazards. We examined the catastrophic loss potential for a repeat of the great San Francisco earthquake; we evaluated the loss potential for a repeat of the New Madrid earthquake; and we estimated the local average annual loss potential due to earthquake throughout the Nation.

Upon review of those figures, it is interesting to compare them with some of the testimony we have heard earlier today. We projected the loss due to a repeat of the great San Francisco earthquake, if it were to occur in 1985, to be approximately $16 billion. Our estimates of the losses from a repeat of the New Madrid earthquake had a large uncertainty. The lower bound to our estimate of building damage was $4 billion. The great uncertainty in this region of the soil effects on strong motion amplification and attenuation could make the losses as much as eight times larger. This results from the size of the area that could be affected and the magnitude of the effects. Considering the greater magnitude now ascribed to a New Madrid earthquake, the building loss estimates are comparable to the numbers that we have heard today.

The State of Washington had the distinction of the highest annual per capita earthquake loss potential of any State in the country.

We certainly cannot predict when a great earthquake is going to occur, but we can examine some of its potential consequences to our Nation's financial institutions. There are many types of insurance other than earthquake insurance against which claims are likely to be made. For example, if I am in my office and an earthquake occurs damaging that building so that a beam falls injuring my back, I would have a claim against my employer's workers' compensation policy. In fact, it turns out—at least for one sample study we performed for a client—that this type of loss may be as great or greater than the building damage.

If I have an automobile that is damaged by that earthquake, I may file a claim against my automobile insurance carrier, or if it is damaged by a collapsing building, I may file a claim against the building owner for third party liability.

Earthquakes may cause dams to fail, which in turn may cause flooding, ensuing casualties, and further building damage. Additionally, pipeline failures may occur causing the release of toxic or combustible gases. Electric powerline failures may cause the failure of life support systems and other critical facilities. An immediate example of this is Mexico City where hospitals collapsed. Computer facilities process control, chemical processes may be disrupted. All of these incidients may cause significant damage beyond the direct earthquake damage.

The failure of the property owner to preclude this type of damage or to mitigate against it may be held as a reason for a third party liability suit, and thus, third party liability insurance may become a very significant portion of the claims.

Let's take a look at the current availability of earthquake insurance. As my copanelist mentioned, the State of California has mandated that companies offering homeowners insurance offer an option to the homeowners to buy earthquake insurance. This is available, but it is available with a deductible equal to the probable maximum loss. For a typical California home, even in the event of a disaster, the homeowner does not obtain protection from his earthquake insurance policy.

In the commercial market, the availability of earthquake insurance has been reduced. Moreover, the limits of liability for policies that are available have been drastically reduced. Premiums have been escalated tremendously, and deductibles have been increased. The consequences of this restricted availability of converage is not limited to just these individual companies seeking protection but has regional and national implications.

At the end of 1983, which is the last time in which data was available from the California insurance commissioner, a catastrophic earthquake in the Los Angeles area would have resulted in approximately $4.7 billion worth of claims. That dollar figure is comparable to the daily trading volume on our Nation's securities exchanges. Thus, in the event of such a disaster we could expect a significant disruption of our national financial markets as the insurance companies proceeded to liquidate the assets necessary in order to pay off those claims.

This is likely to depress security prices and cause further diversion of investment from the normal economic activity of our Nation into the recovery operation.

A further consequence is the potential for mortgage default. Particularly in the absence of adequate earthquake insurance or in the absence of the possibility of rapid response on the part of the Federal Government, the destruction of property and the interruption of business reduces the capability of individuals and small businesses to honor their payments to loan holders. This increases the possibility of a mortgage default, since the property itself forms the collateral. The advent of a large number of small regional banks who concentrate their loan activities within small geographical regions increases the likelihood of bank failures.

This is further complicated by the dependence of banks on electronic data processing for transaction processing and recordkeeping. Formerly, transaction were slower and written records were used with ample backup records. Increasingly, we depend on computers to manage transactions and recordkeeping. While large institutions are developing backup offsite computer facilities at remote locations, small institutions cannot presently afford to take these steps. Thus, at the time when these small institutions will have their resources stretched to the maximum, their ability to manage their business will be further hampered by the lack of adequate records.

Those are the major points I wish to make.

Thank you.

[The statement follows:]

STATEMENT OF JERRY HABER, NATIONAL TECHNICAL SYSTEMS

EARTHQUAKES, INSURERS AND SELECTED FINANCIAL INSTITUTIONS

Three major points will be presented with regard to the insurance/financial industry and earthquakes:

1. An individual attempting to protect his home or business against earthquake losses will find adequate coverage difficult to obtain and expensive in today's market.

2. If a great earthquake were to occur today a significant number of the claims recieved by insurance companies might derive from policies not designed to cover earthquake losses.

3. The impact of a great earthquake on financial institutions will not be confined to insurance companies. The banking system will be affected by the destruction of property securing loans. Insurance company liquidations of holdings in the financial markets to satisfy claims will have a major impact on these markets.

Today the insurance industry is in the retrenchment portion of the underwriting cycle. Even prior to the Mexican earthquake, as a consequence of large underwriting losses, reduced investment profits and years of low premium levels the insurance industry has a significantly reduced underwriting capacity. The heavy losses have been aggravated by the litigious nature of our society. Foreign reinsurers have paid claims in the United States disproportionately high to the premium income they were deriving in this country; moreover, many domestic reinsurers have suffered severe losses. The result is that the primary (direct) insurance underwriters have significantly reduced underwriting capacity and that they must ask higher premiums for the coverage which they do offer. The claims from the Mexican earthquake will further reduce the capacity in the reinsurance market.

Although these factors apply across all lines of insurance, the effects are particularly dramatic for those lines characterized by low probability, high magnitude losses, such as product liability, professional liability and earthquake insurance. Some companies are unwilling to write earthquake insurance. Those who are willing to do so demand highly restrictive terms.

Coverage for commercial property has been available only with drastically reduced limits of liability. Rates and deductibles have risen. In California, earthquake insurance for dwellings has a limited availability. The typical policy deductible is set at ten percent of the value of the coverage. Coverage is typically available for a minimum limit of liability of $100,000. This coverage is frequently available only to purchasers of homeowner's policies.

This type of coverage has limited value to the homeowner. Much of the construction in this area is wood frame or wood frame with stucco. The Probable Maximum Loss (PML) for this class of structure when built on rock or firm natural ground is judged by industry to be 10 percent (As a point of reference, the mean damage level for wood frame residential structures affected by the 1971 San Fernando Valley earthquake was 5 percent). Thus, because the typical deductible is set at the PML level these policies have minimal value. Furthermore, since the median value of improvements for a single family dwelling is less than $100,000, the majority of California homeowners do not achieve any protection by buying this type of policy. The policy is of some value to homeowners who own dwellings of poorer construction (e.g., with cripple wall studs or unreinforced masonry walls) or dwellings not located on competent soil.

Since 1978 the California Department of Insurance has required insurers to report their aggregate liability incurred by writing earthquake insurance and their estimated Probable Maximum Losses (PML). This reporting was established in order to assure the public that the insurance industry would have adequate reserves to satisfy claims resulting from a great earthquake. In order to begin to assess the magnitude of the problem, the Department of Insurance made a number of compromises. The complexities of the underwriting of large commercial accounts are not reflected in the Department's methodology. Moreover, all structures of a given type were assumed equally vulnerable to earthquake damage regardless of their actual proximity to fault zones or type of soil on which they were constructed. Finally, rather than requiring independent audits, as are required for financial statements, the insurers report their own liabilities. The Department of Insurance did, however, make the provision that alternative methods of reporting might be proposed to the Department. National Technical Systems (NTS) developed a method of simulating an earthquake and estimating the resulting losses and their impact on an insurer's

portfolio. This method was approved by the Department of Insurance in 1979. Since that time, we are one of two independent organizations approved by the State of California to perform these analysis.

Even though the actions taken by the State of California, Department of Insurance were an important step in mapping the liabilities of the insurance industry in the event of a great earthquake, it is important to recognize that it is only a first step. California is only one of several states that could be affected by a great earthquake. Earthquake insurance is only one of several lines of insurance under which claims may be filed in the event of an earthquake. Although, at this time a thorough evaluation of the magnitude of the claims that would arise under other lines of insurance has not been made, the dollar value of claims from the non-earthquake policies could be significantly greater than the claims under earthquake policies.

An initial indication of the magnitude of this problem was obtained by an earthquake Probable Maximum Loss (PML) study for workers compensation claims performed by NTS for one of its clients for whom a previous analysis had been performed of earthquake policy PML. Some of the other lines of insurance that may be affected include life insurance, medical insurance, automobile insurance and third party liability insurance. (While elimination of the doctrine of concurrent causation in California reduced the number of types of insurance under which earthquake damage claims may be filed there, the courts in other states may not have ruled on the doctrine of concurrent causation. Thus, outside of California there may be, for example, claims under a standard homeowner's policy. Moreover, claims under the listed lines of insurance might occur in California or elsewhere.)

Third-party liability claims could be a contender for the major source of claims in the wake of a great earthquake. An earthquake produces three types of damaging effects: shaking, ground failure and water waves (seiches or tsunamis). These in turn damage real estate, improvements and other manmade objects in the area. Damaged structures may cause death or injury to their occupants. The damage interferes with an occupant's ability to conduct his business and may, given a sufficiently long interruption, put him out of business. Dam failures caused by earthquakes may cause extensive flooding and consequent casualties and property loss. Direct damage to utility or industrial pipelines may release combustible or toxic gases creating the hazards of fire or poisoning. Loss of electric power may damage life support systems. Damage to hospitals, process control computers and data processing centers may have life threatening or, at least, severe economic consequences. An argument may be made that the owner of the damaged property is liable for these effects, for failing to preclude or mitigate their consequences.

The most recent (end of 1983) publicly available estimate from the California Department of Insurance of insured losses from a great earthquake in the Los Angeles area is $4.66 billion. Even if this represented all lines of insurance under which claims would be made (and as discussed earlier it is only a fraction of the total), $4.66 billion is comparable to the daily dollar volume of trading on the country's major financial markets. Thus, the need for massive liquidations of securities and other investments in the weeks and months following the disastrous event might disrupt orderly trading on these markets, depress the average value of assets held both by the insurance industry and others and result in further massive diversion of capital from normal investment opportunities to recovery and repair activities.

The final major threat to the financial stability of major institutions comes from potentially high rates of mortgage defaults in areas severely affected by earthquakes and the further possible failures of marginally viable banks or savings and loan institutions. When a dwelling or business sustains severe damage in an earthquake, if the owner's personal resources, insurance or disaster relief is not fully adequate to meet restoration/recovery needs the owner may not be able to engage in necessary property repairs. This may force the mortgages into default. The likelihood of default may be increased by business interruption losses and the accompanying temporary or permanent unemployment. Since the property is the lender's collateral, if the damaged property's value is less than the outstanding balance a loss will be incurred by the lender. Small savings and loans and banks are especially vulnerable to these losses because they tend to concentrate their loans within a small geographical area. Moreover, with the advent of electronic banking financial institutions now depend heavily on computer systems. While the larger institutions are developing geographically dispersed backup systems to allow them to continue functioning in the event of an earthquake the smaller institutions are less capable of providing this backup capability. Thus, they may face the potential threat of loss of records and resulting confusion at a time that they most need their records to manage their uncertain loan portfolio and to control withdrawals of deposits.

Management of these problems requires (1) addressing the insurance industry's capacity problem, (2) a more complete definition of the earthquake induced losses that insurers may face in lines of insurance other than earthquake insurance, (3) an assessment of the earthquake induced mortgage default problem, (4) development of effective backup computer capacity for the financial industry and (5) development of an orderly procedure for insurance companies to liquidate securities after a massive disaster so that there is no "run on the market".

[The following information was subsequently received for the record:]

QUESTIONS OF SENATOR GORTON AND THE ANSWERS

Question 1. You have outlined in your testimony rather significant problems related to: the availability of earthquake insurance; the exposure of insurance companies to claims resulting from a catastrophic earthquake; the effect of such an earthquake on other financial institutions.

In your opinion, what options should be considered for a federal role in helping to mitigate these effects:

Answer. There are several important roles the Federal government must take to mitigate these effects. Definitions of the optimum long term solution is a complex problem which requires a benefit/risk analysis of individual options and sets of options to all affected parties. A follow-on investigation to our 1981 study for the Federal Insurance Administration should be initiated to provide Congress with these long term guidelines. Because of the catastrophic loss potential should a great earthquake occur in the meantime, we cannot afford to wait for a definition of the optimum policy. Thus, although definition of the optimum policy will require an extension to our study, I will define some interim solutions that Congress can enact now.

The single most effective role the Federal government can play is to foster loss control mitigations. A reduction in the catastrophic loss potential protects the public, reduces the need for earthquake insurance, reduces the expected value of insurance claims, reduces the likelihood of loan defaults, and reduces the impact of claims handling on the nations securities markets. It has been estimated that an effective mitigation program could reduce losses by 25 to 50 percent. (In terms of the building losses for a repeat of the great San Francisco earthquake that would amount to more than $4 billion savings.)

I believe that an effective incentive can be provided to property owners through a combination of low-interest loans (priced at the government's cost of money plus transaction costs) plus tax credits. This combination of incentives would foster seismic retrofit without discriminating against "cash-poor" individuals. The only costs to the government would be the foregone revenues resulting from the tax credits. Even this cost is more apparent than real. Implementation of the retrofit program would employ people, promoting the local economy and enhancing the Federal tax base.

In order to facilitate indentification of effective mitigations and to minimize abuse of this program a simple set of guidelines should be developed to identify earthquake mitigations which may be certified as effective by building inspectors. This should be supplemented by a procedure to allow a registered professional define alternative effective mitigations.

A second step the Federal government can take is to promulgate interim regulations for lending institutions to minimize the impact of catastrophe-induced loan defaults. The key to these new regulations is the dollar loss each institution can sustain without posing a serious risk to its financial stability. Each institution would be required to demostrate that it has an earthquake disaster preparedness plan to assure its financial integrity. Provisions of the plan would include preventative measures and remedial strategies. Candidate remedial strategies might include mortgage default insurance (covering earthquake) or a hazard induced loss sharing pool with other geographically dispersed lending institutions. One preventative measure is to require borrowers to establish that their residual equity is greater than the probable maximum loss that an earthquake will cause. Another measure would be for the lending institution to establish that its loan portfolio had an adequate geographical spread to preclude its financial demise in the event of a great earthquake.

The Federal government will, in one way or another, be the insurer of last resort. It will either develop an effective partnership with the insurance industry to assure the public adequate protection through earthquake insurance and the insurance industry adequate reserves to settle claims, or it will face the burden of funding post-

disaster relief and reconstruction to the afflicted communities. The issues associated with the optimal Federal role are complex and a definition of that policy should use our 1981 study and subsequent research funded by the Federal govenment as a point of departure.

Presently, I believe that an effective element for assuring insurance companies an adequate spread as part of that Federal role is the development of natural hazards insurance and promulgating appropriate regulations to assure its widespread sale throughout the country. A natural hazards policy (or endorsement) would provide protection against wind (hurricane, tornado, and severe winds), water (riverine flooding, storm surge, and tsunami) and earth (earthquake, expansive soil, and landslides) hazards. Their use of a geographically diversified all-natural hazard policy would significantly broaden the underwriting base and provide a mechanism for "smoothing" the annual variation in claims costs. It is anticipated that natural hazards' insurance would attract a significantly broader policy holders' base than earthquake insurance alone does. Ultimately, I believe this broader market would alleviate much of the earthquake insurance related capacity problem faced by the insurance industry. The optimum combination of this and other possible solutions must await a conclusion to an extension of our 1981 study.

Question 2. Associated with your company is Dr. John Wiggins who in 1981 completed a study requested by the Federal Insurance Administration, on options open to the federal government for involvement in an earthquake insurance program. Have major changes occurred since 1981 that we should consider when reading this study? Are there areas of study that should be conducted as logical follow-ups, or extensions of, the "Wiggins Report"?

Answer. In our 1981 study for the Federal Insurance Administration a number of policy problems related to eathquake insurance were identified. Candidate Federal roles were identified in that study including fostering development and implementation of earthquake loss mitigation measures; acting as a reinsurer of last resort or providing "catastrophe" loans to insurers; and requiring recipients of federally-backed loans to purchase earthquake insurance. The study workshop participants ranked the candidate Federal roles based on their subjective assessments of effectiveness in solving the policy problems. It is not surprising that workshop participants rated loss mitigation meaures as the single most important Federal role. Effective loss control significantly reduces the magnitude of losses which would result from a catastrophe. Nevertheless, implementation of loss control measures will take time and will be met with a certain amount of resistance from those who must bear the costs of the mitigation efforts. Consequently, other supplemental measures must be implemented to provide protection to property owners and to insure the viability of our nation's financial institutions. Some of these were identified in our 1981 study. A follow-up study should be conducted which defines the benefits and risks to the various stakeholder groups of various federal roles and policies.

It is important that the study be broad enough in scope to address all lines of insurance which may be significantly affected by an earthquake (for example, auto, inland marine, mortgage default, third party liability) and all stakeholders in the decision process. The costs, benefits and roles that will be required of Federal, state and local agencies must be addressed. But before these governmental roles can be defined, the defacto losses which would be sustained by different segments of the economy from possible great earthquakes throughout the country must be assessed. Our company, U.S.G.S., the National Science Foundation and FEMA have previously performed important segments of this loss assessment. These studies should be reviewed in conjunction with ongoing research funded by these agencies. It should be updated and supplemented as necessary to provide a basis for the analysis. While a complete and ongoing assessment of the relationship of losses to governmental roles is important to assure the effectiveness of these mitigation programs, it must not be allowed to unduly delay the initiation of effective action.

The study should include an evaluation of the opportunities and restrictions proposed policies impose on land owners, insurance companies, banks and the securities markets. It should address the time phasing of the implementation of alternative options. While abrupt institutional changes can cause disruption of the smooth functioning of governmental and private institutions, delay in the implementation of necessary mitigations increases the risk of a catastrophic earthquake in the interim. This would not only affect the property owners suffering damage but would contribute to the national deficit and attack the GNP.

Senator GORTON. Thank you all very much. We appreciate your testimony on a particularly difficult aspect of this issue. We do have a number of questions for each of you, but in light of the

hour, we are not going to ask them now. We will submit them to each of you in writing and hope that you will enlighten us by answering them in writing for us for the record.

Thank you very much.

We are adjourned.

[Whereupon, at 1:30 p.m., the subcommittee recessed subject to the call of the Chair.]

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